

Evaluation of Cloud Description in Climate Models using A-Train Observations

Hélène Chepfer

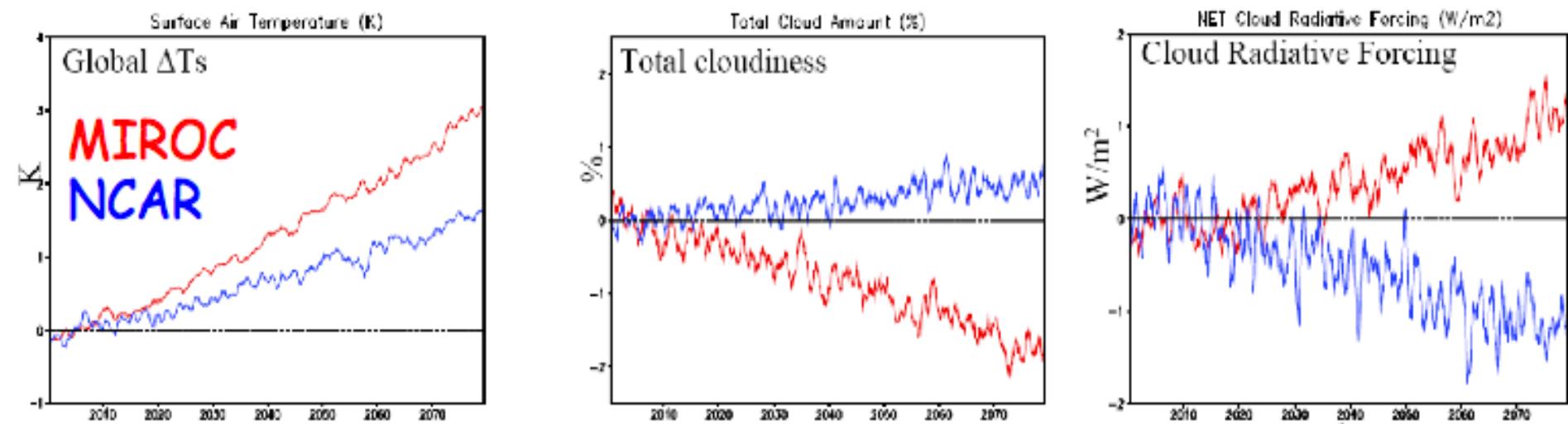
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A. Bodas-Salcedo, (UKMO)**

Clouds & Climate Change

Projections of future climate for 2 different climate models



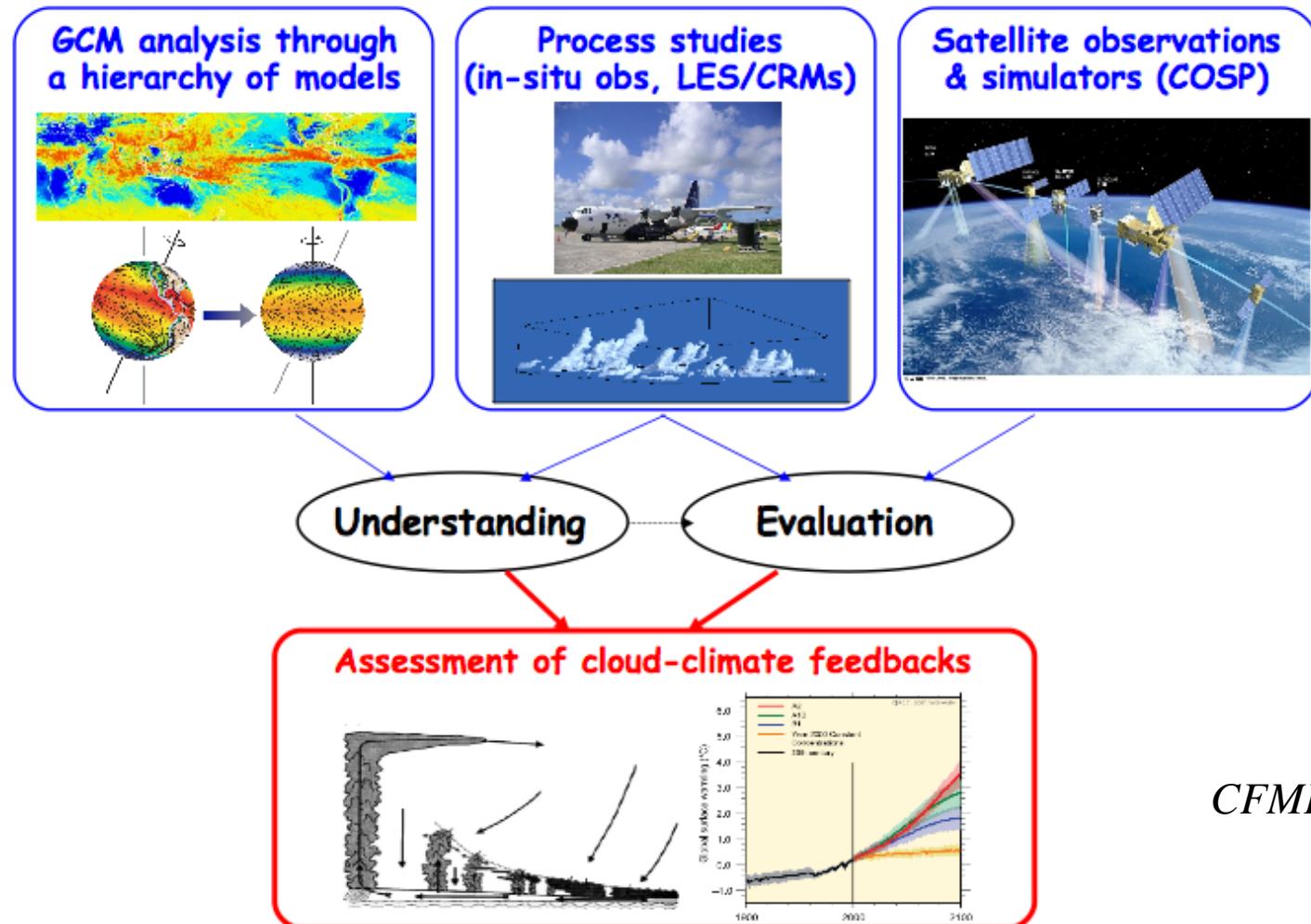
Clouds : a key uncertainty for model-based estimate of future climate evolution

i.e., Randall et al. 2007, Dufresne and Bony, 2009, Soden et Held, 2006, Webb et al., 2006, Ringer et al. 2006



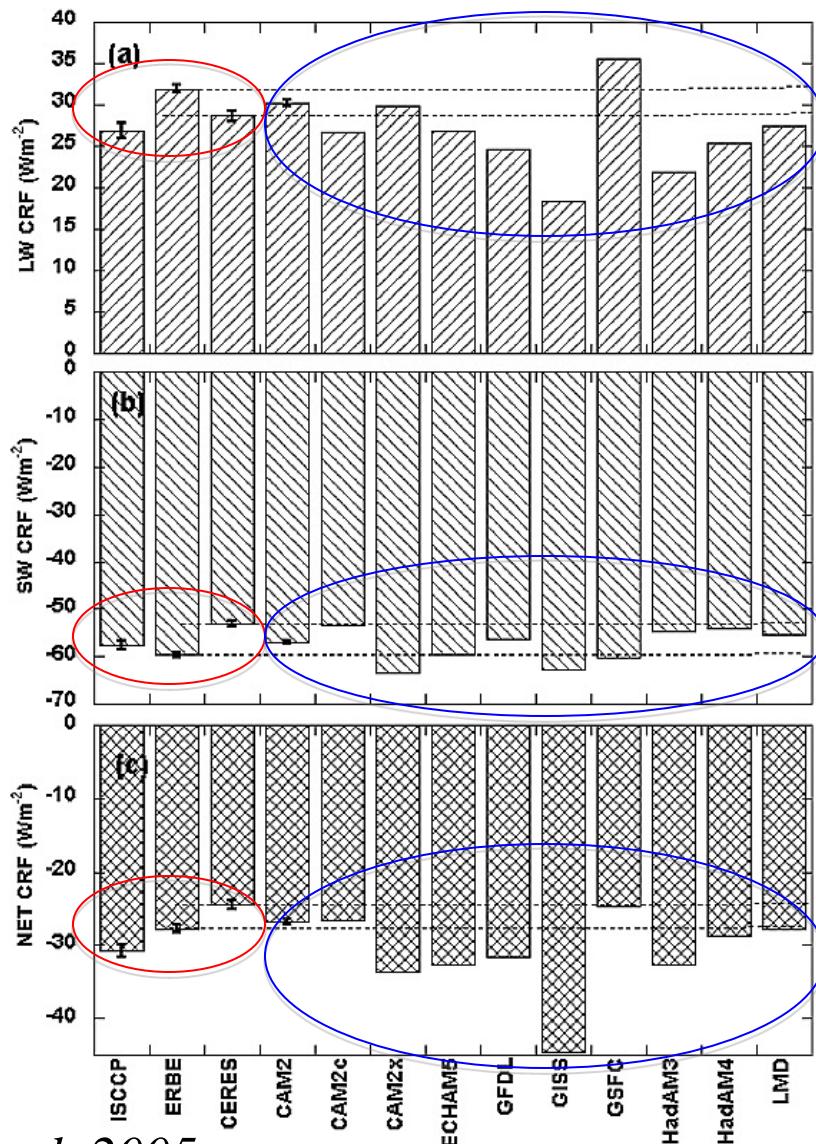
Need a thorough evaluation of cloud description in climate models

Various complementary approaches to evaluate clouds in climate models



Ground based and Satellites Observations contribute to the evaluation of cloud description in climate models

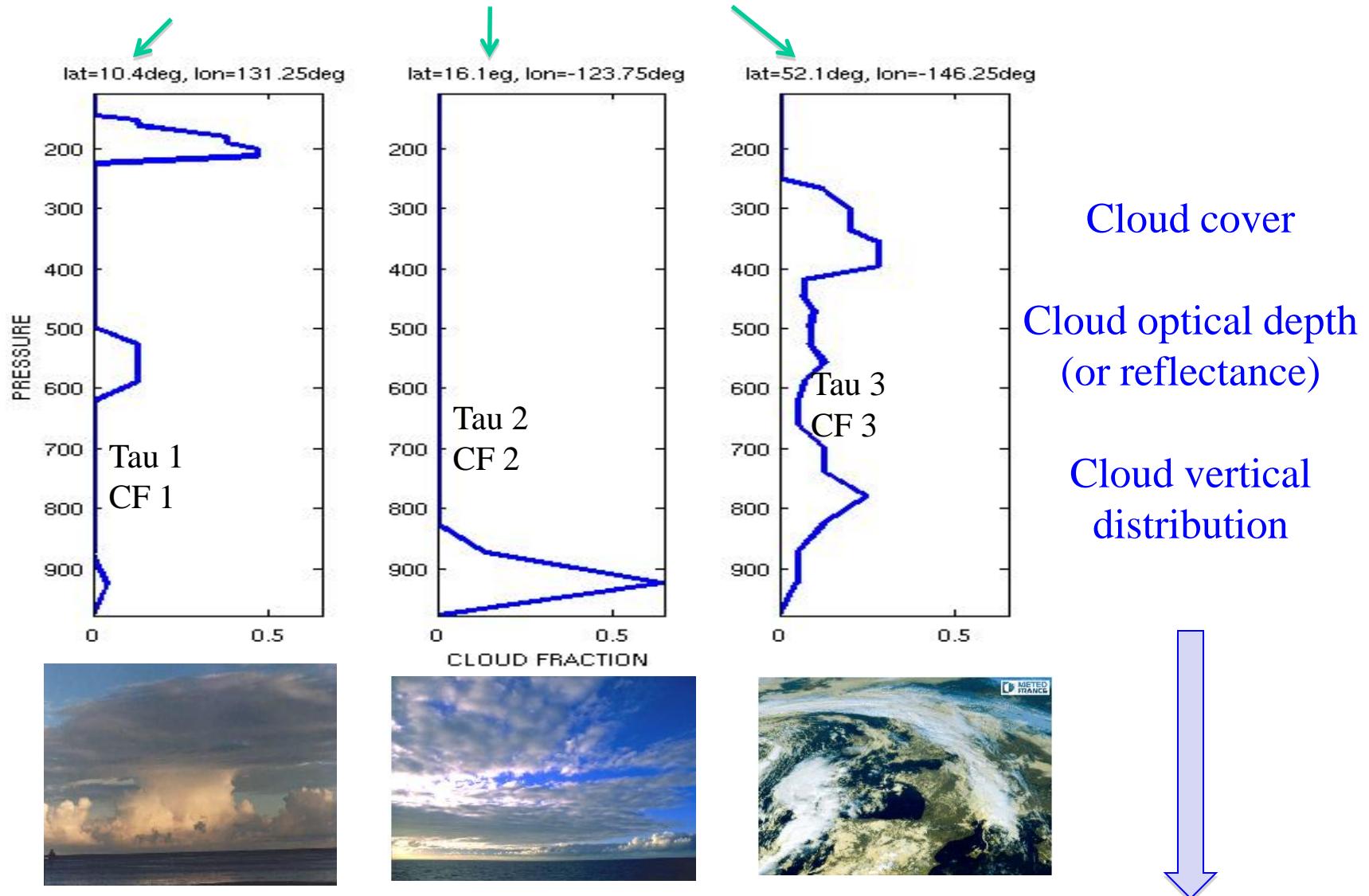
How did Satellites contribute to the evaluation of clouds in climate models, before the Atrain ?



Fluxes observed by Satellite (ERBE, ScaRaB, CERES, ISCCP) are widely used to ensure that the monthly mean energy balance is correct at the top of the atmosphere.

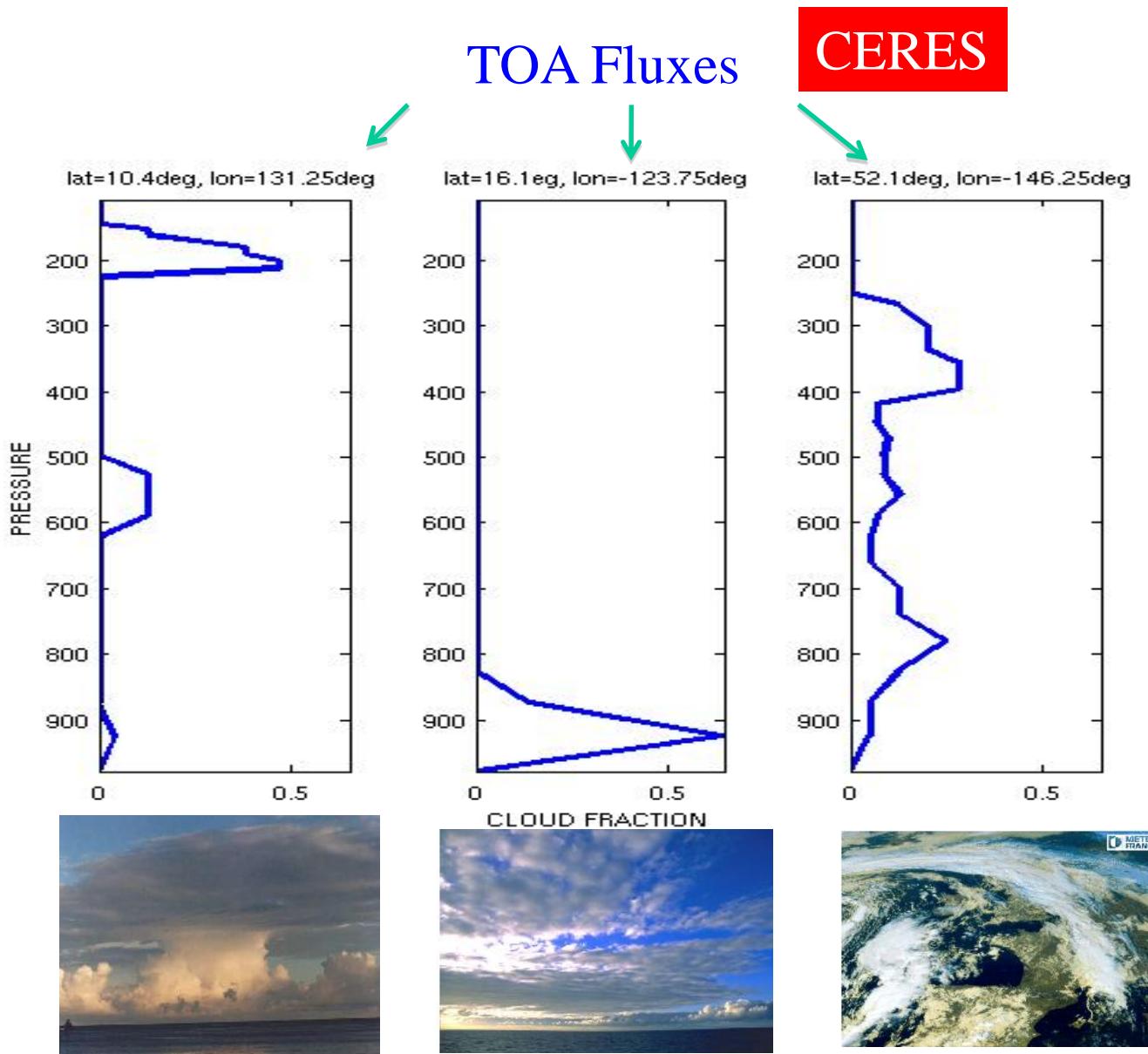
+ ISCCP histograms

But ... a given TOA Flux can be produced by different cloud types



GCM can produce correct TOA flux for wrong reasons because of errors compensations

The Atrain can unravel error compensations in climate models



Cloud vertical
distribution

Calipso/CloudSat

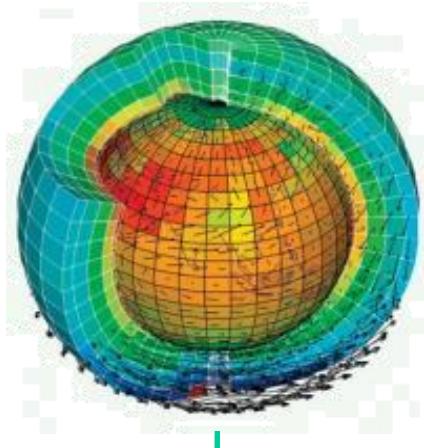
Cloud optical depth
(or reflectance)

Parasol/Modis

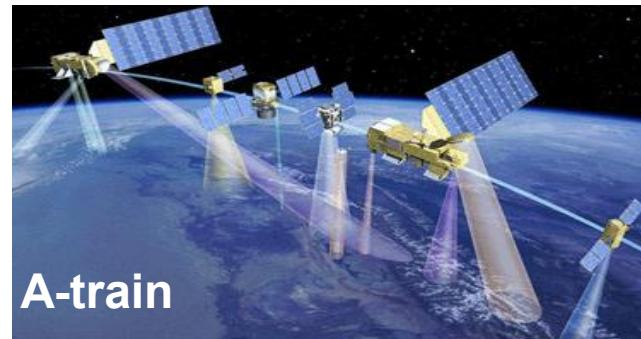
Cloud cover

All... Calipso

The approach for comparing A-train observations with climate models



not consistent



Observation Simulators: COSP

Calipso, CloudSat, Parasol, Modis,
Ceres, Isccp, Misr

-A joint effort UKMO, LMD/IPSL, LLNL, CSU, UW

Dedicated Obs dataset: CFMIP-OBS

Calipso, CloudSat, Parasol, Modis,
Ceres, Isccp, Misr

-A joint effort LMD/IPSL, LOA,
NASA/LaRC, LLNL, UW

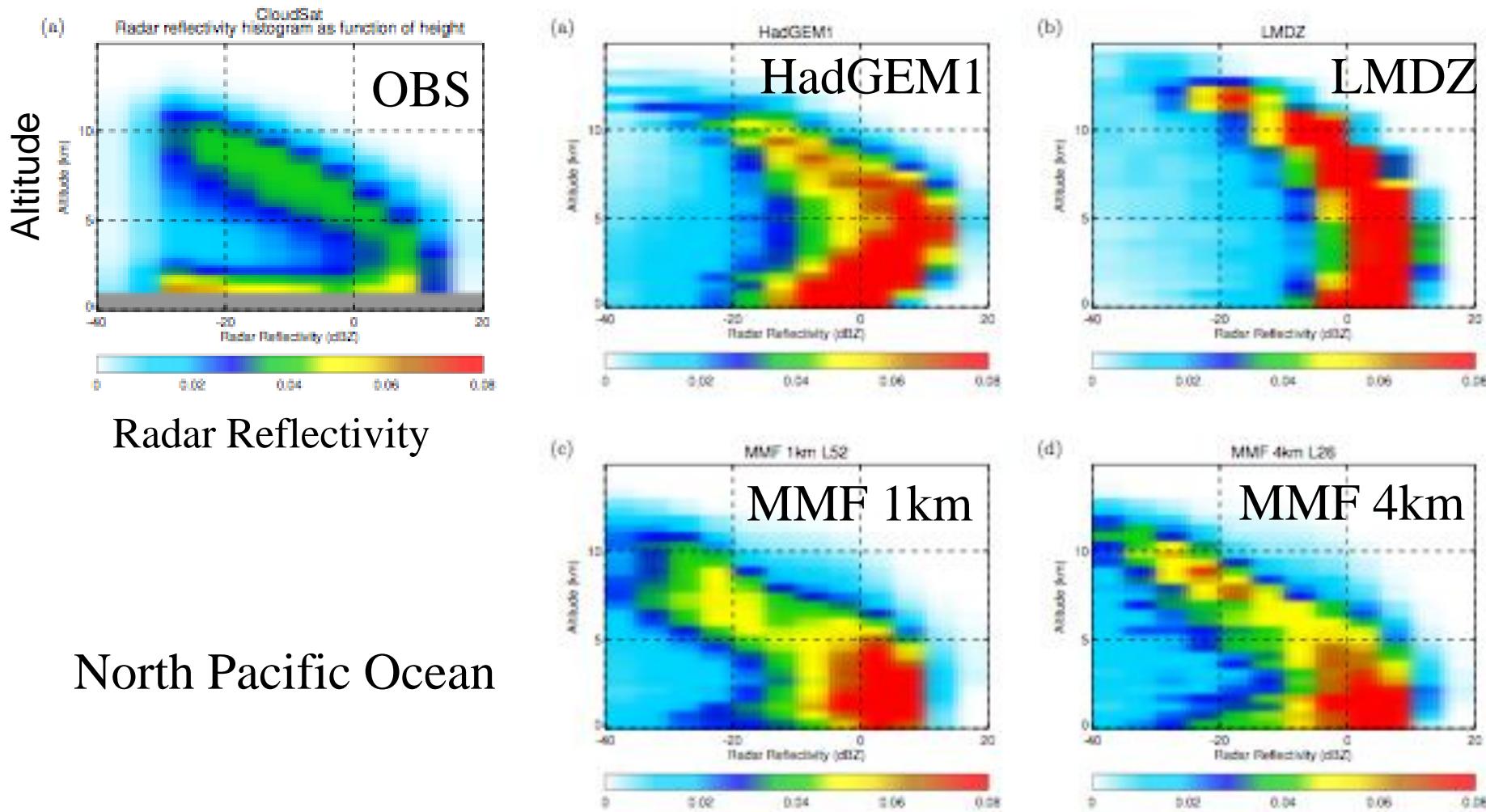
Simulated dataset

consistent

Observed dataset

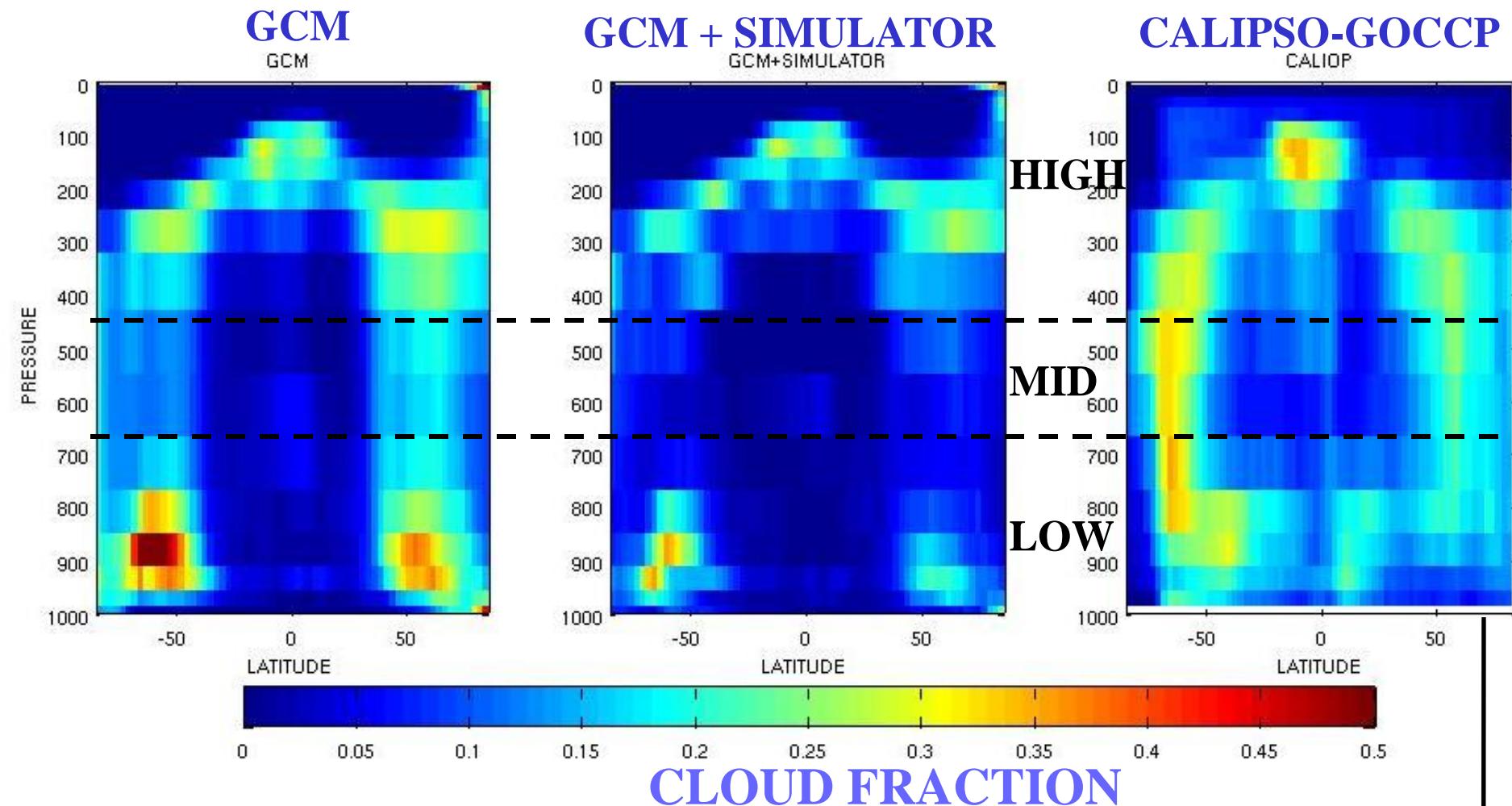
Ensures that model/obs differences are due to model deficiencies

Evaluate the hydrometeor distribution with CloudSat



Bodas, Webb, Bony, Chepfer, Dufresne, Klein, Zhang, Marchand, Haynes, Pincus, « COSP: satellite simulation software for model assessment », submitted to BAMS

Evaluate the cloud vertical distribution with Calipso



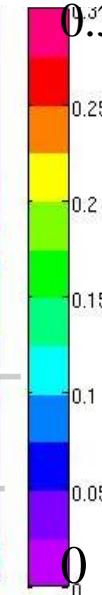
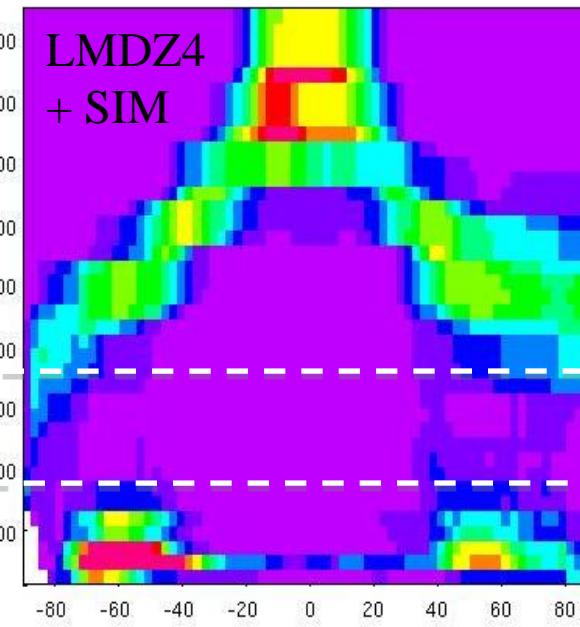
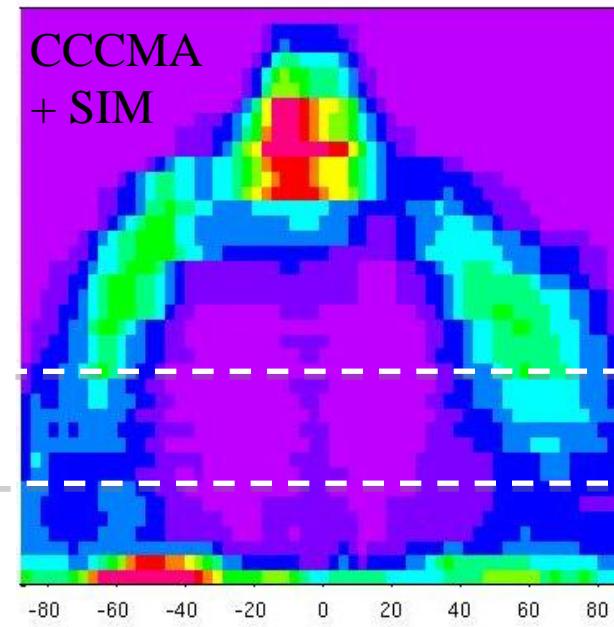
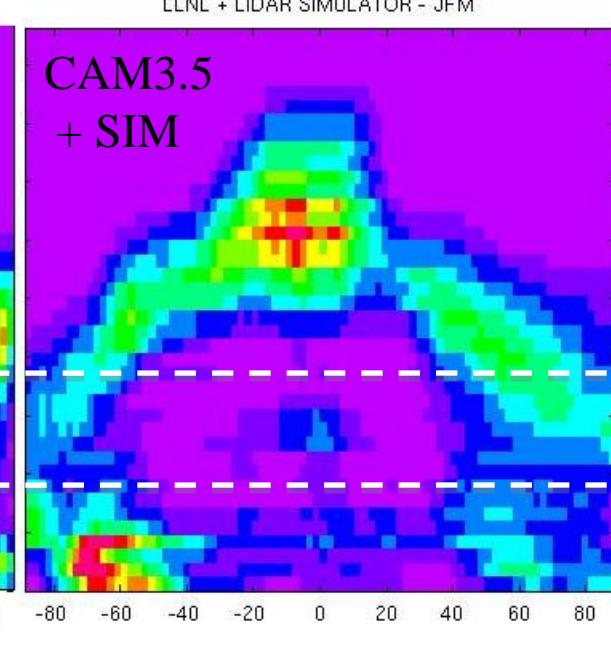
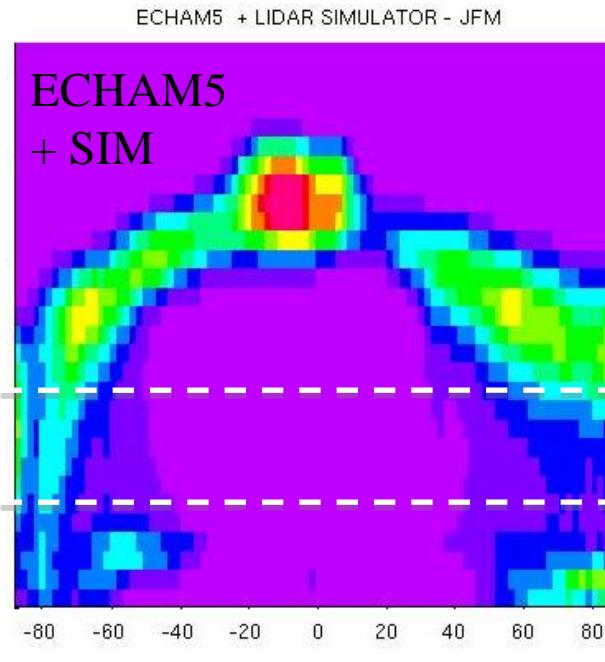
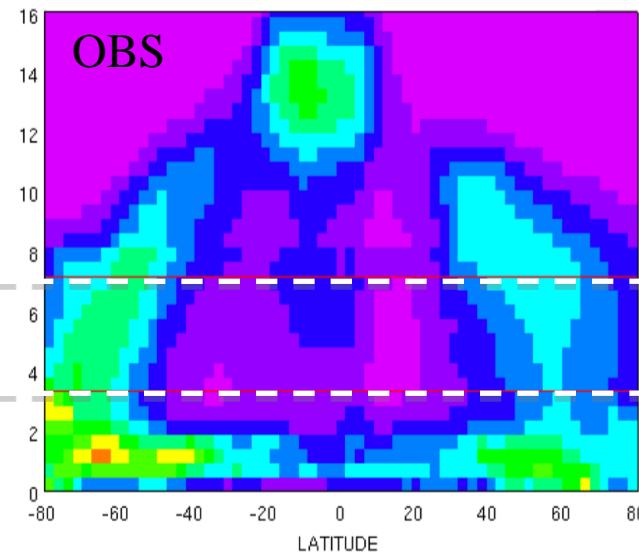
Chepfer et al., GRL, 2008

Poster by G. Cesana,
H. Chepfer, D. Winker, B. Getzewich

Evaluate the Cloud Vertical distribution

CALIPSO-GOCCP

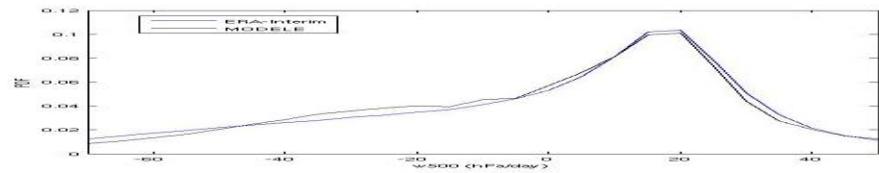
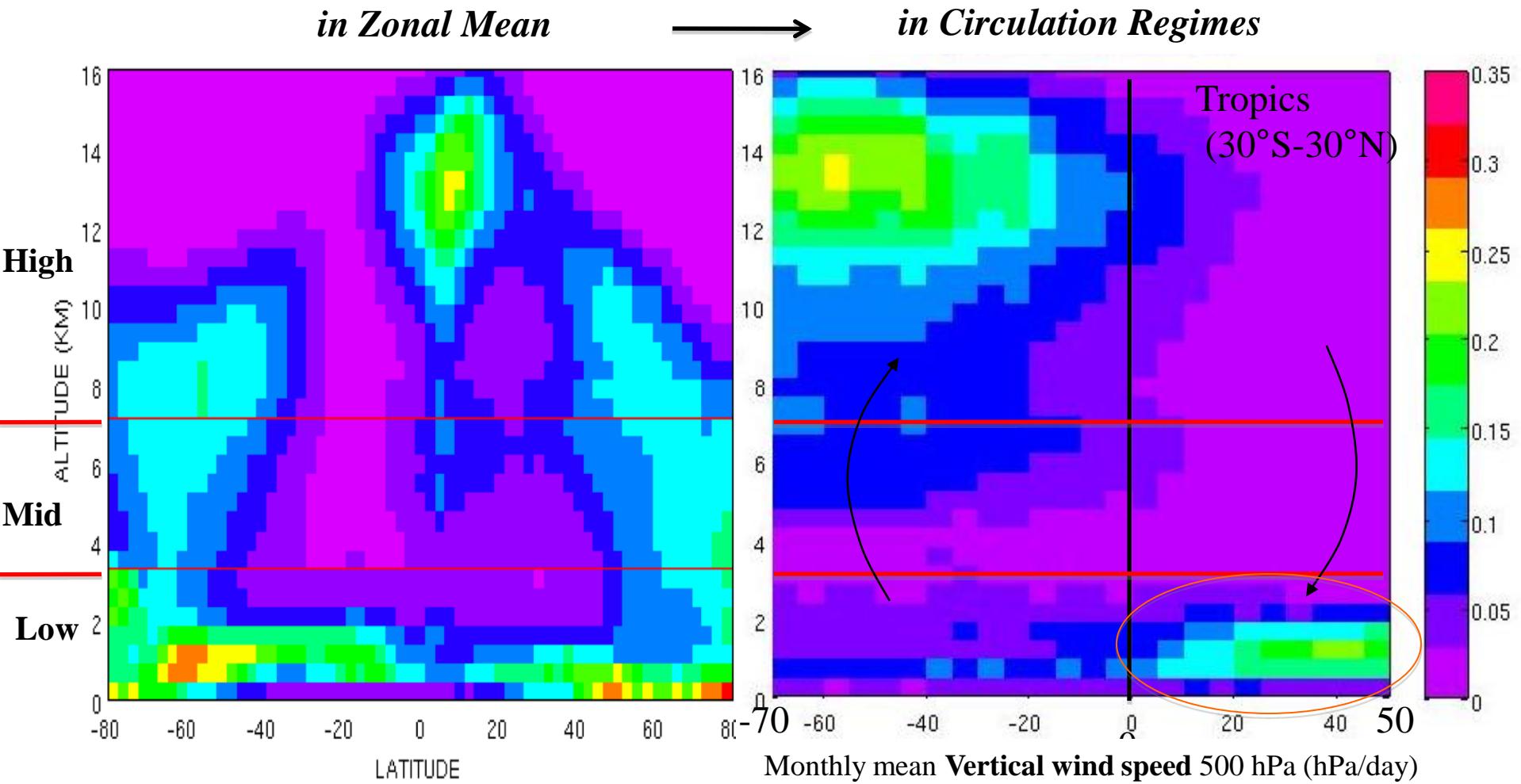
(Chepfer et al. JGR, 2010)



- Overestimated:**
- High clouds
- Underestimated:**
- Tropical low clouds
 - Congestus
 - Mid level mid lat

Cloud vertical distribution

- Observations CALIPSO-GOCCP -



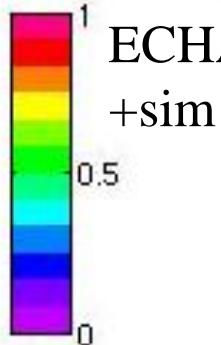
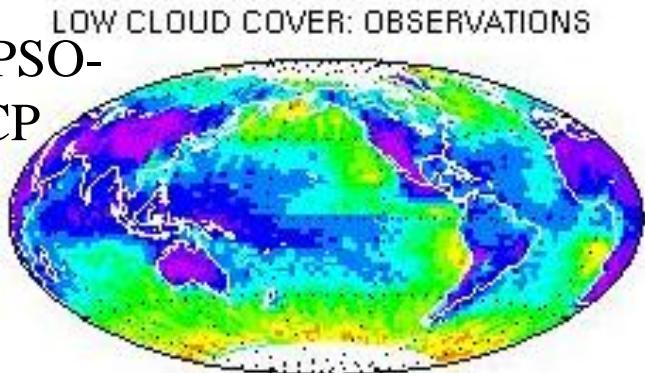
The low level clouds in subsidence regions :

at the heart of tropical cloud feedback uncertainties
in climate models

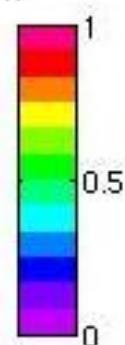
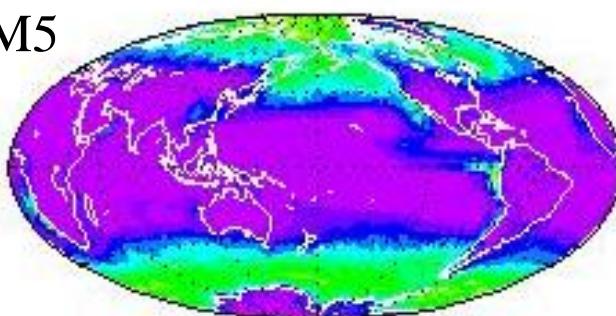
(Bony and Dufresne, 2005)

Evaluate the Low Level Clouds

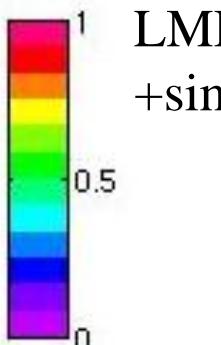
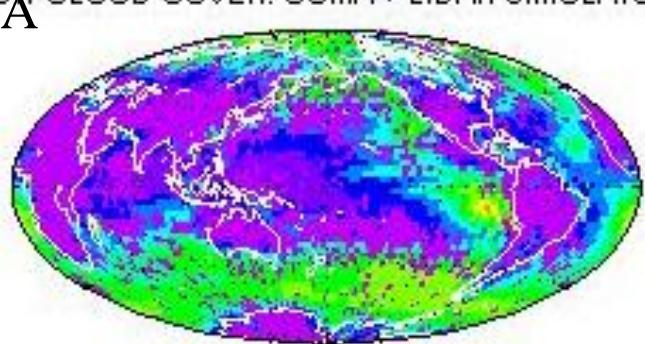
CALIPSO-
GOCCP
OBS



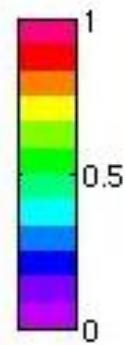
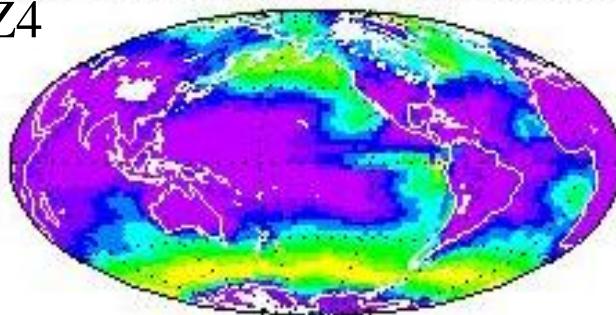
LOW CLOUD COVER: ECHAM5 + LIDAR SIMULATOR



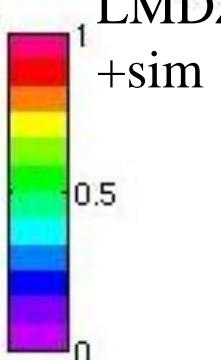
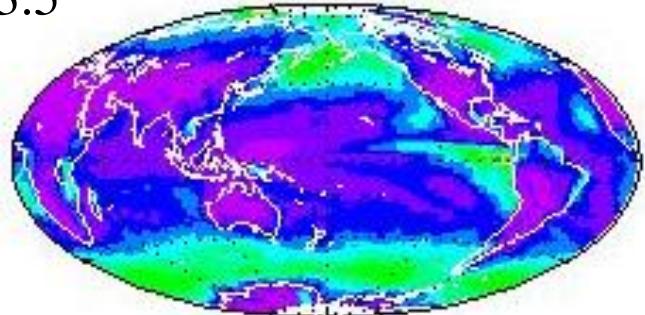
CCCMA
+sim



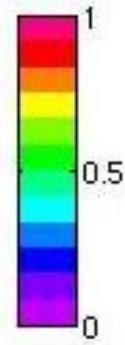
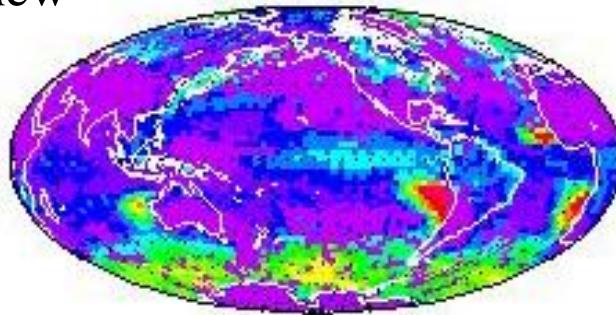
LOW CLOUD COVER: IPSL + LIDAR SIMULATOR



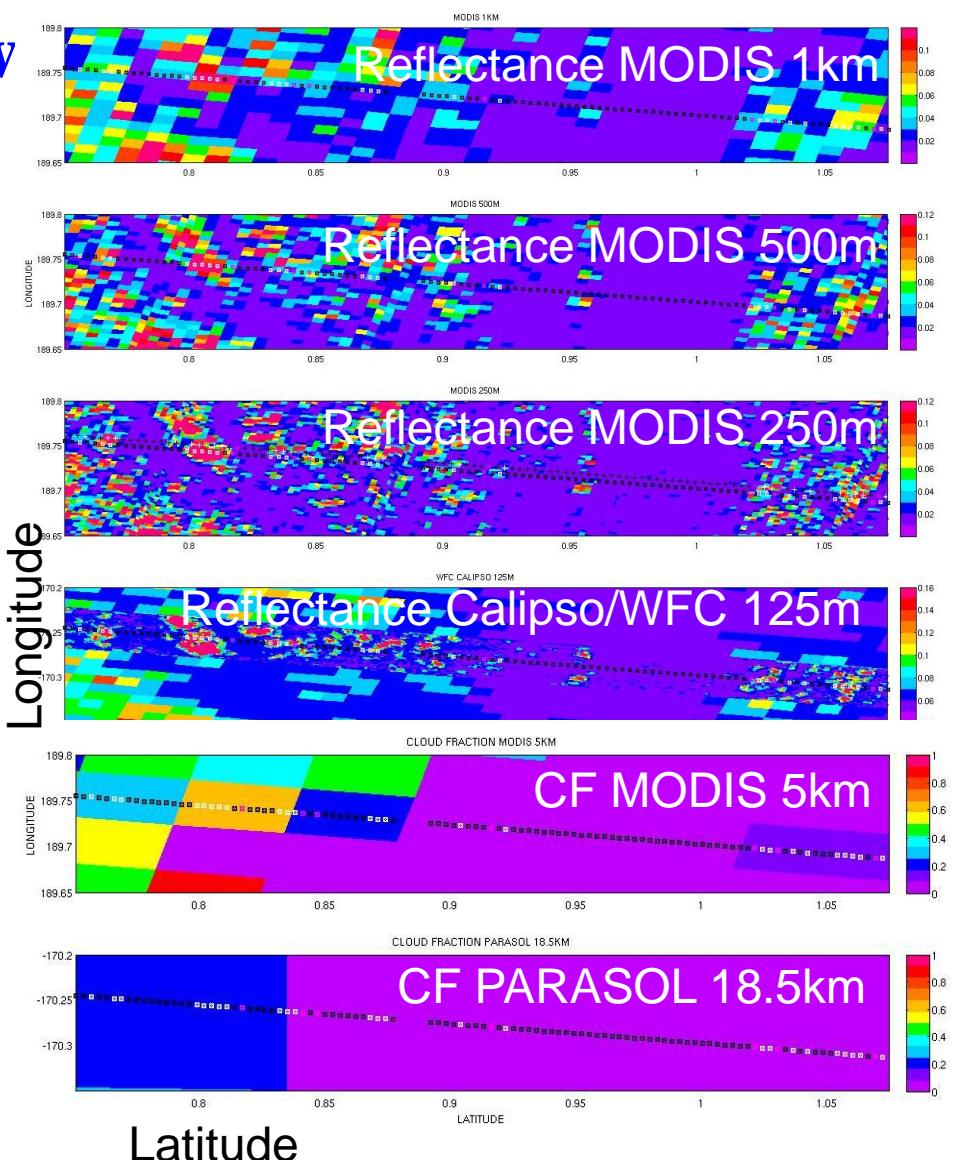
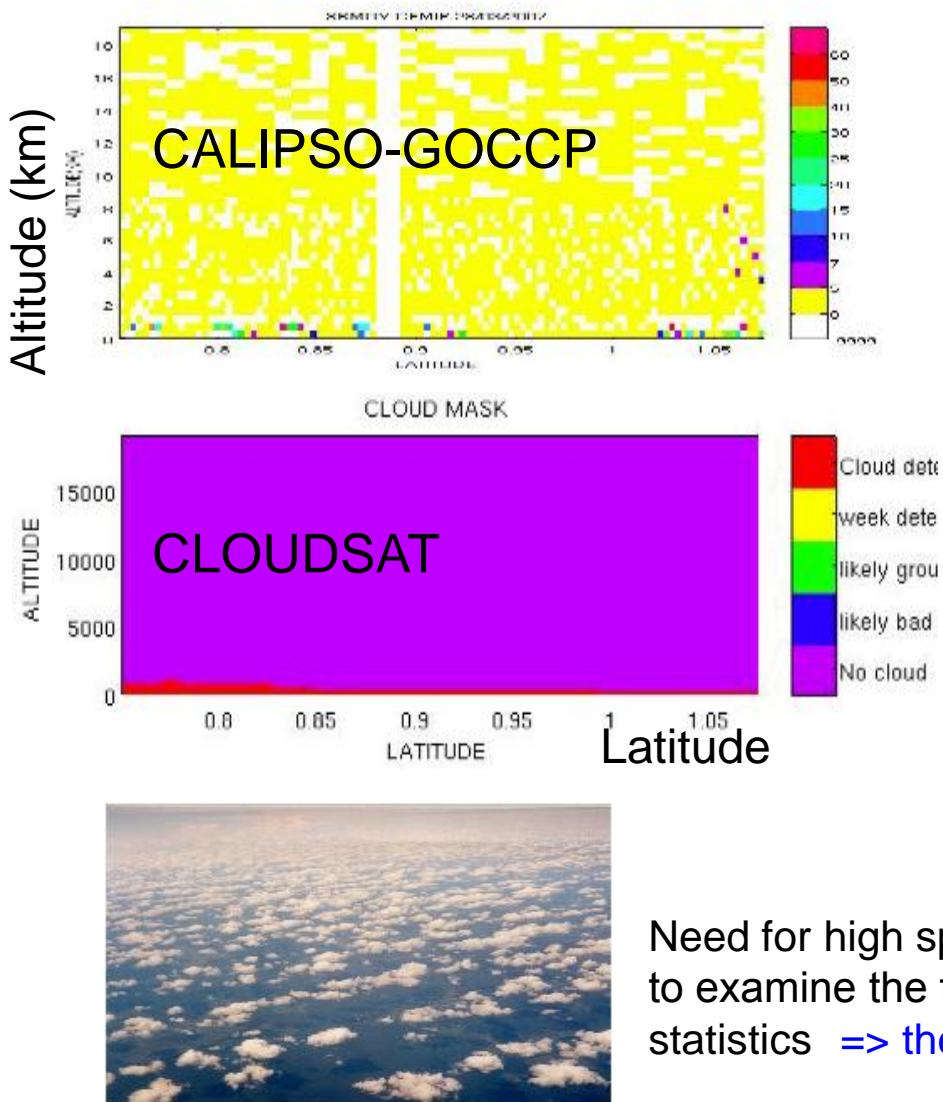
CAM3.5
+sim



LOW CLOUD COVER: IPSL-new physics + LIDAR SIMULATOR



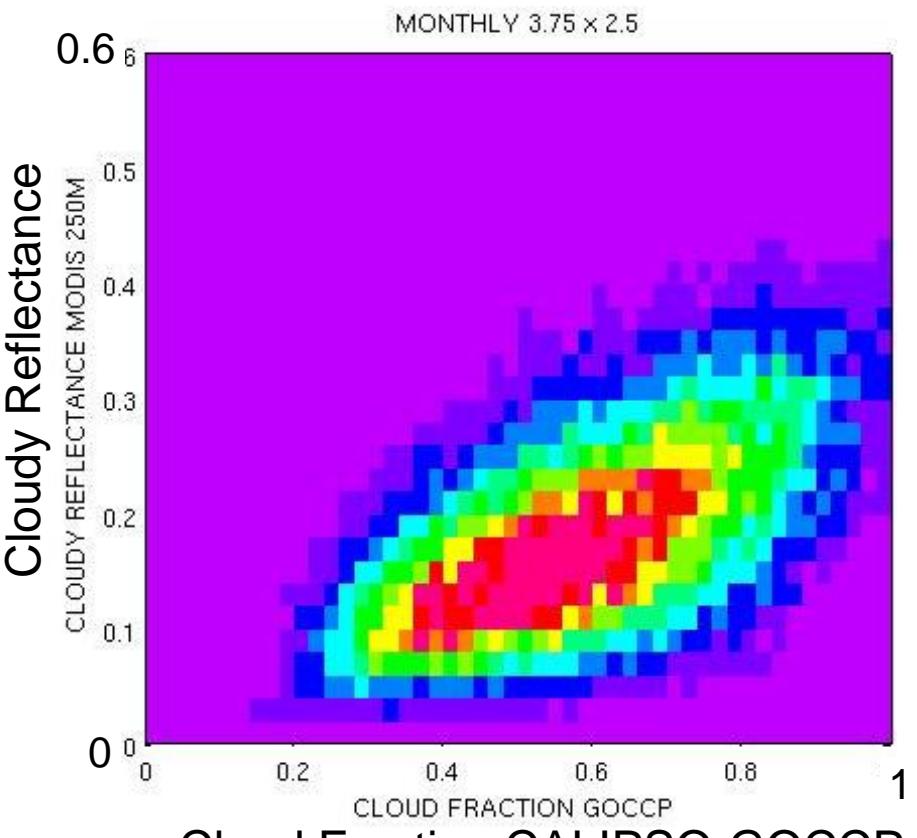
How do the Low level shallow cumulus clouds look like in A-train observations ?



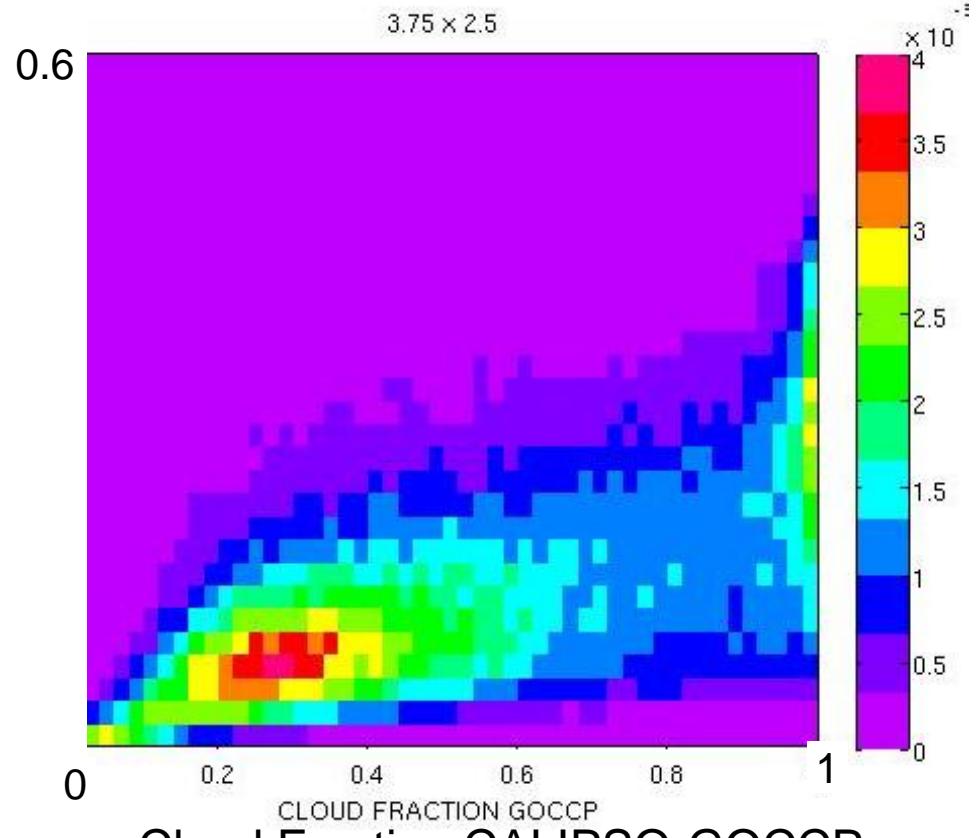
Need for high spatial resolution, instantaneous and colocated obs to examine the fractionated low level clouds ... and global scale statistics => the full A-train capabilities are required

Cloud Cover and Cloud Optical Depth over Tropical Ocean

Monthly mean observations



Instantaneous Observations

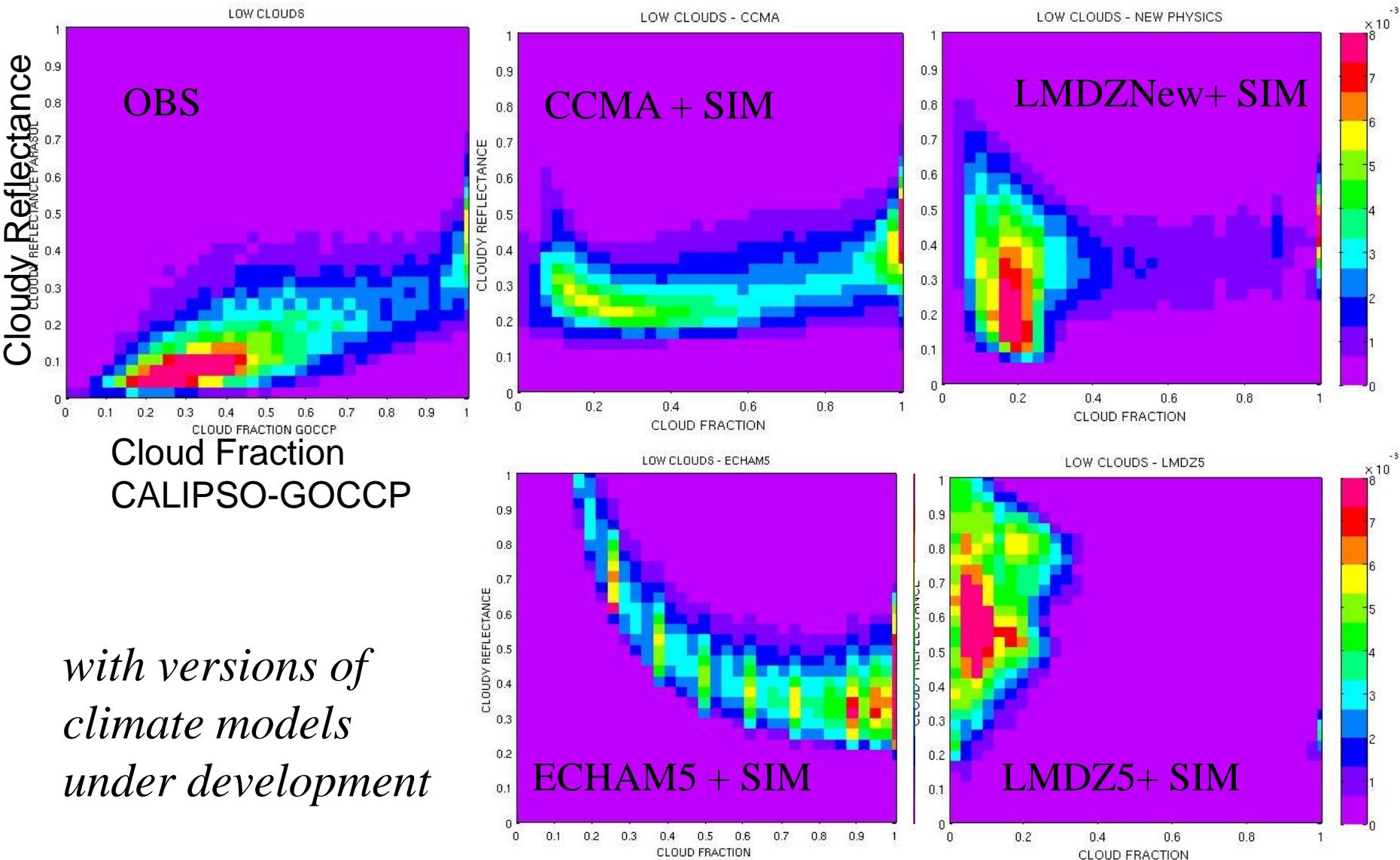


In the observations, the instantaneous “state of the atmosphere” is significantly different of the monthly mean one

→ The A-train gives a picture of the instantaneous state of the atmosphere at global scale

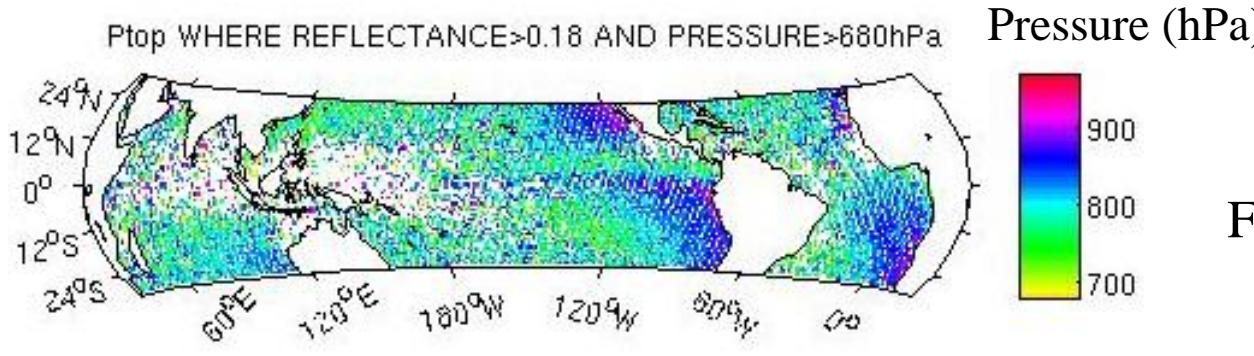
Cloud Cover and Cloud Optical Depth over Tropical Ocean

- Instantaneous – Low level clouds only

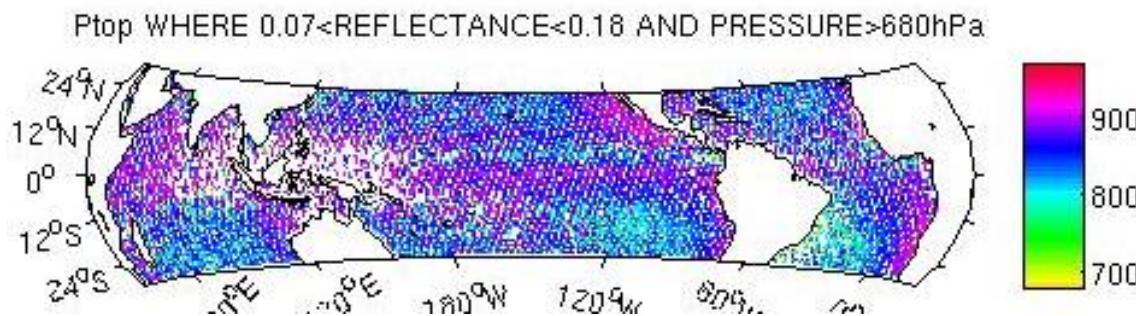


Cloud top pressure in boundary layer tropical clouds

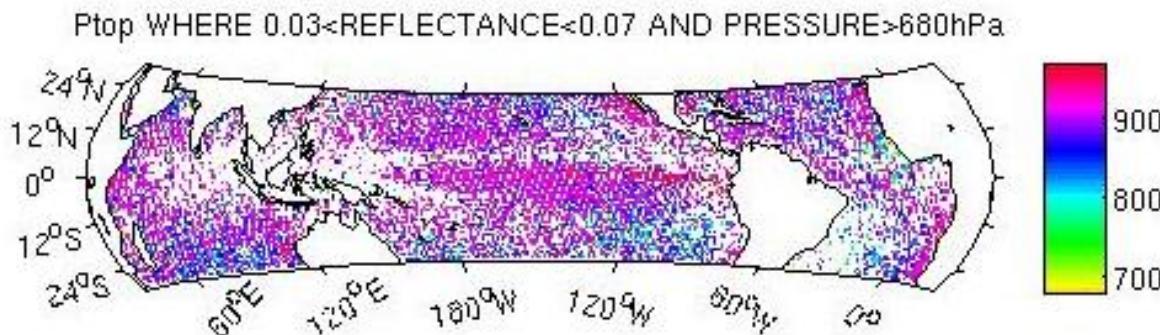
(Ptop from Calipso-GOCCP, Reflectance from PARASOL)



For clouds with $\tau > 3$



For clouds with $1 < \tau < 3$

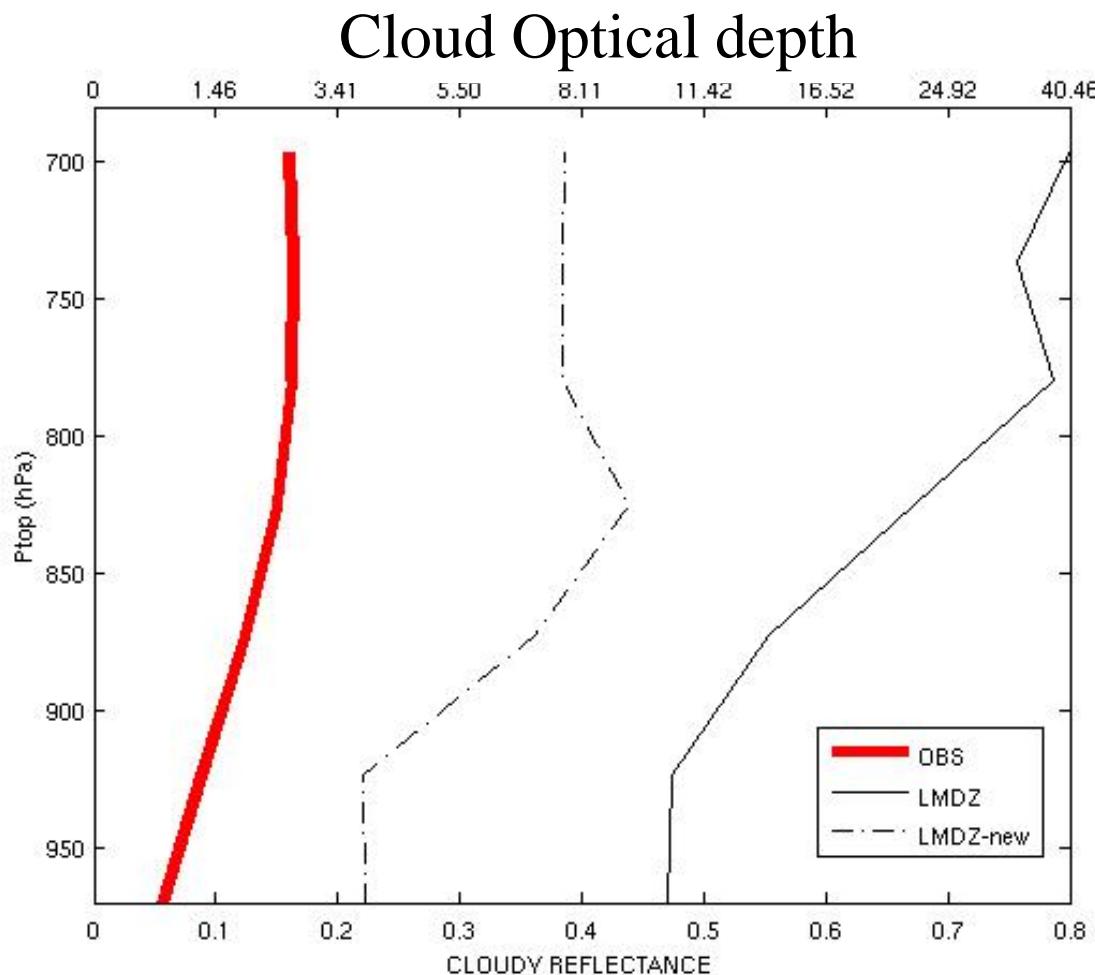


For clouds with $\tau < 1$

(Konsta et al. submitted)

In observations, cloud top gets higher with optical depth

Cloud top level, Cloud optical depth and Cloud fraction - in low level tropical clouds -



Cloud Top
Pressure
Calipso-
GOCCP

Cloud Reflectance

For $0.2 < \text{Cloud Fraction} < 0.5$
Statistics over 2 years

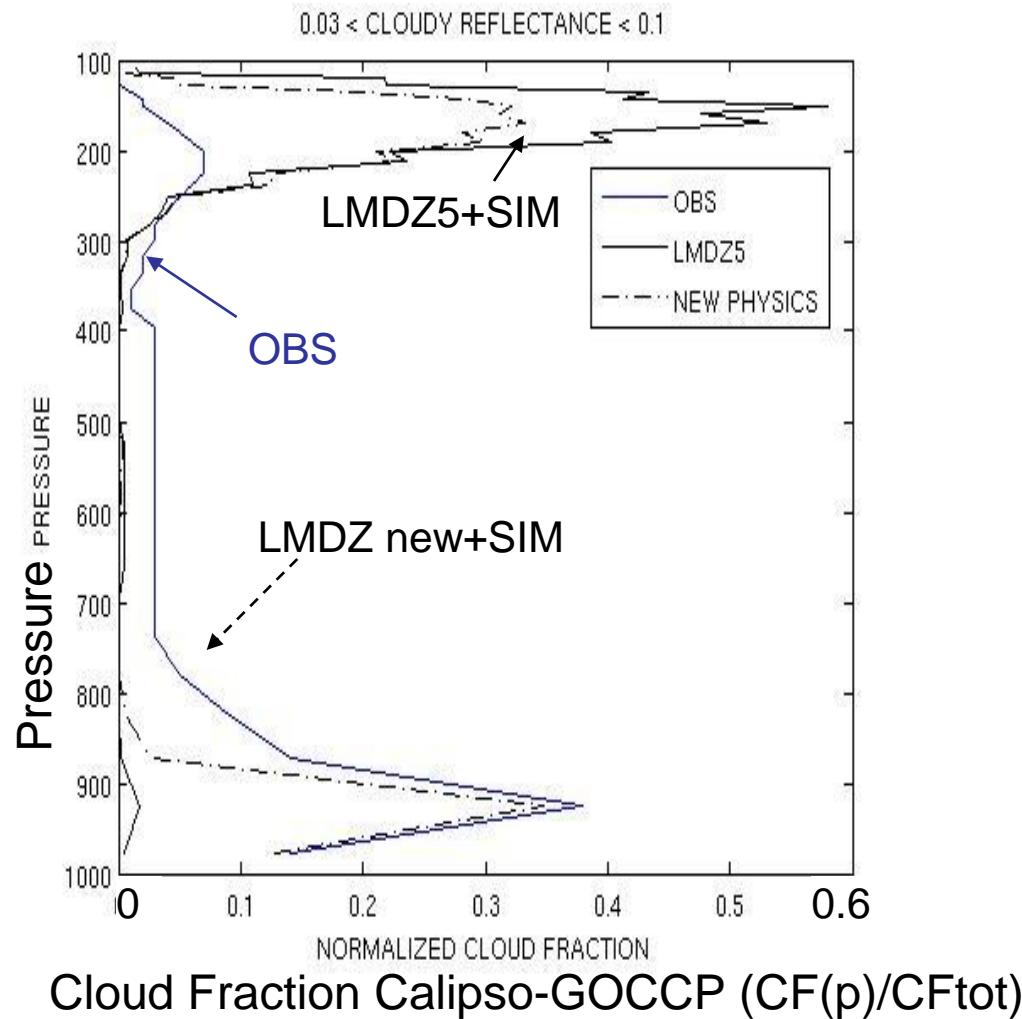
(Konsta et al. submitted)

What about the others clouds ?

Cloud Cover versus Vertical distribution versus Cloud Reflectance

Tropical ocean

OPTICALLY THIN CLOUDS ONLY : $\tau < 2$

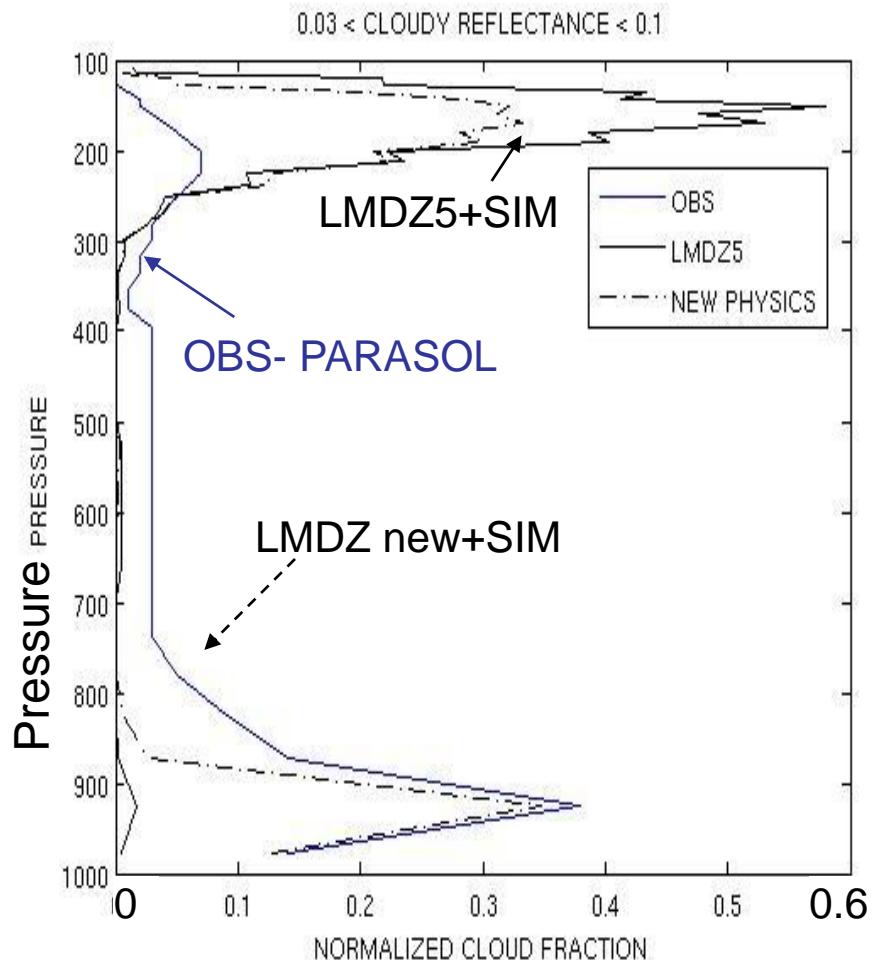


Error compensations in the models between cirrus and shallow cumulus

Cloud Cover versus Vertical distribution versus Cloud Reflectance

Tropical ocean

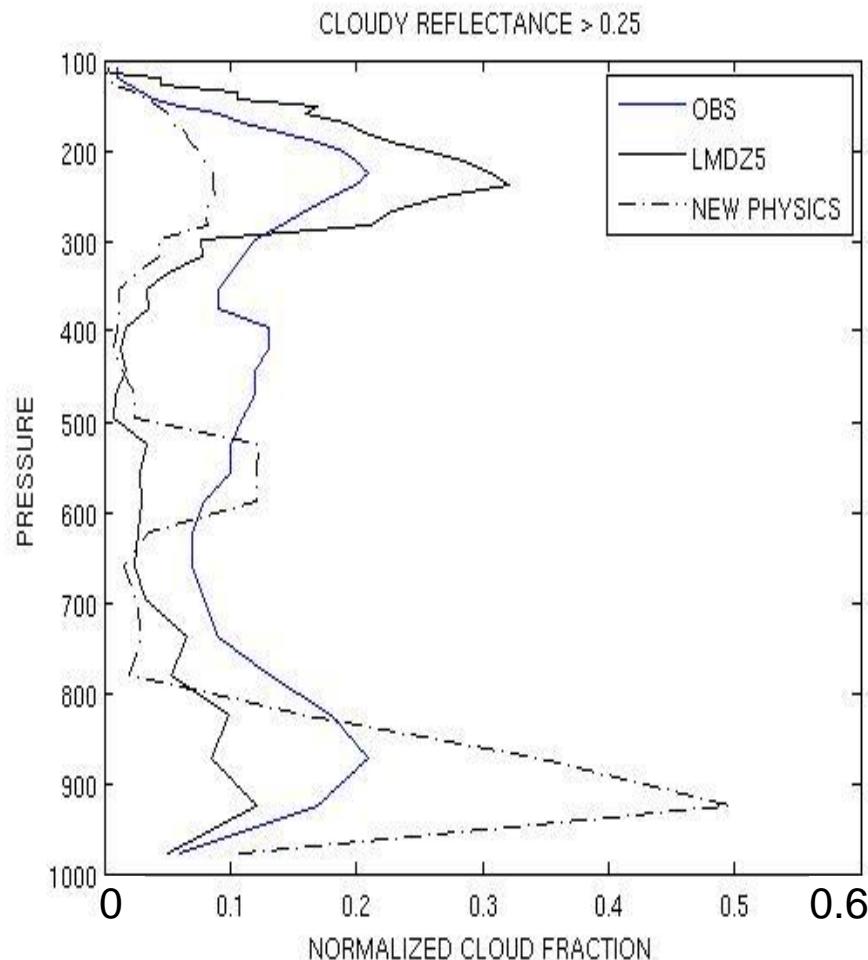
OPTICALLY THIN CLOUDS ONLY ($\tau < 2$)



Cloud Fraction Calipso-GOCCP
(CF(p)/CF_{tot})

Error compensations in the models for all cloud types

OPTICALLY THICK CLOUDS ONLY ($\tau > 5$)



Cloud Fraction Calipso-GOCCP
(CF(p)/CF_{tot})

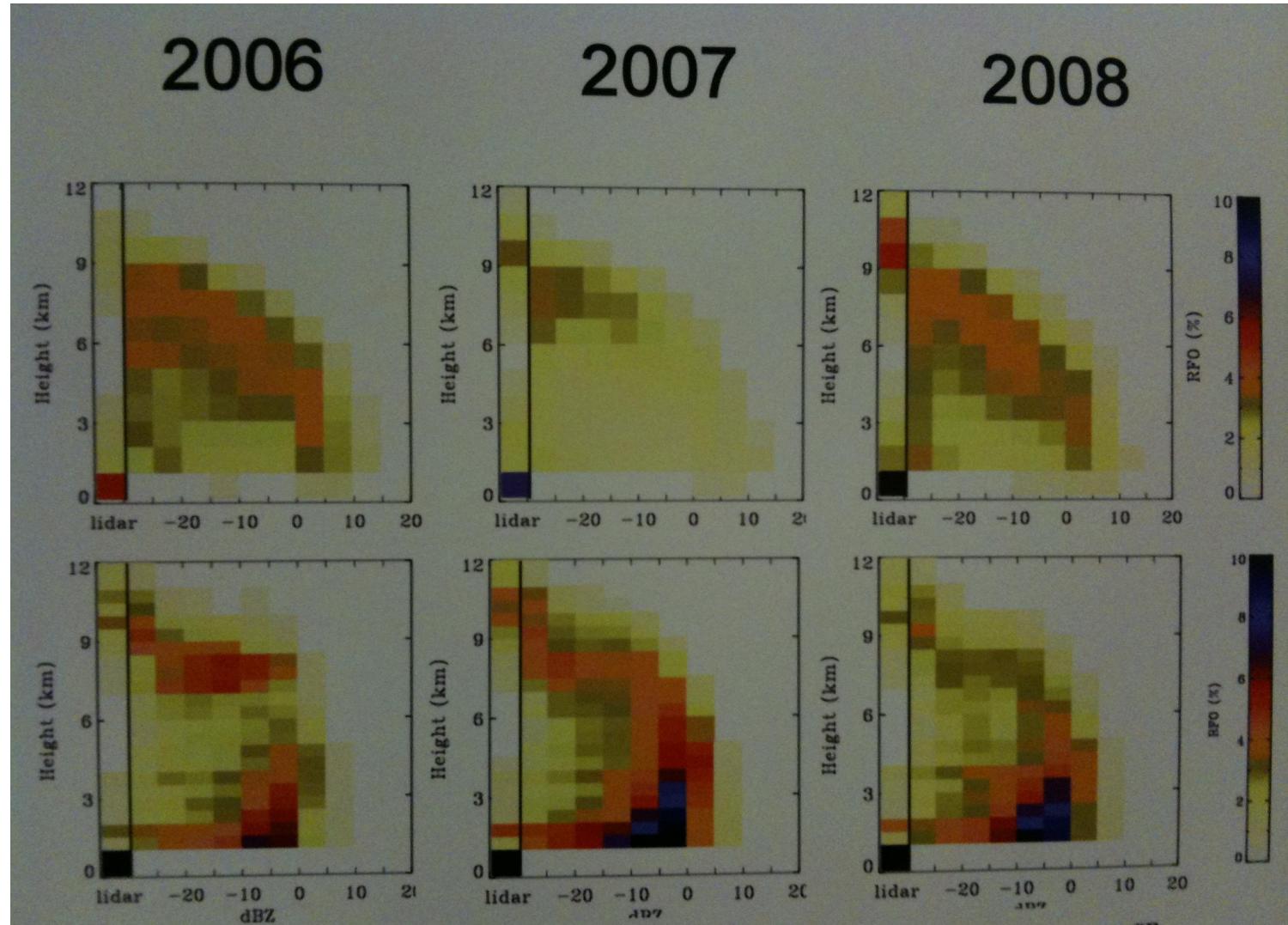
(Konsta et al. submitted)

Arctic clouds, over the region of 2007 unprecedent sea ice loss

JJA

OBS

CAM3.5
+ COSP



Y. Zhang et al. poster

The model shows an unrealistic cloud response in sea ice loss

Conclusion

The Atrain is a powerful tool to evaluate cloud descriptions in climate models

The Atrain allows to unravel in climate models, error compensations between cloud fraction, optical depth, vertical distribution, instantaneous/monthly

When used statistically at high spatial and temporal resolutions, the colocated Atrain observations, do not only evaluate climate models but also provide an unprecedented statistical view of clouds at the process scale... this is needed to understand cloud processes and to suggest leads for cloud parameterization improvements in climate models.

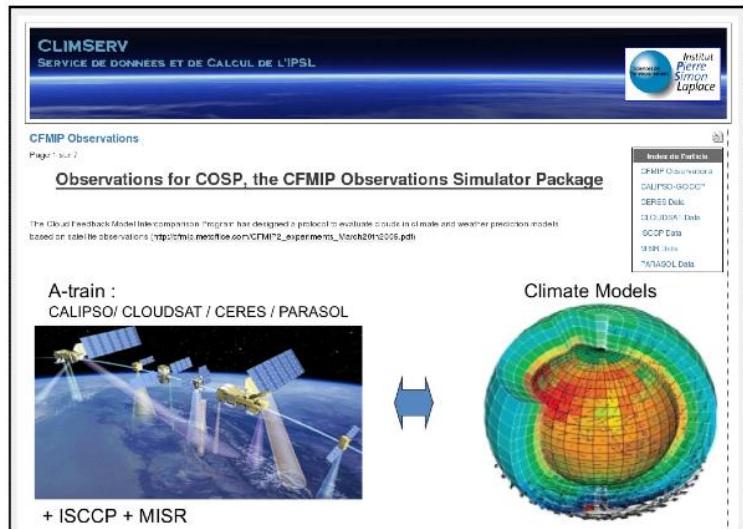
In this talk, we mostly highlighted the added value of the Atrain for tropical low level clouds for which the models exhibits significant biases

... but similar A-train / climate models analysis are on the way for others topics i.e. high clouds, polar tropospheric clouds etc...

The potential of Atrain for evaluation/improvement of cloud descriptions in climate models is huge !

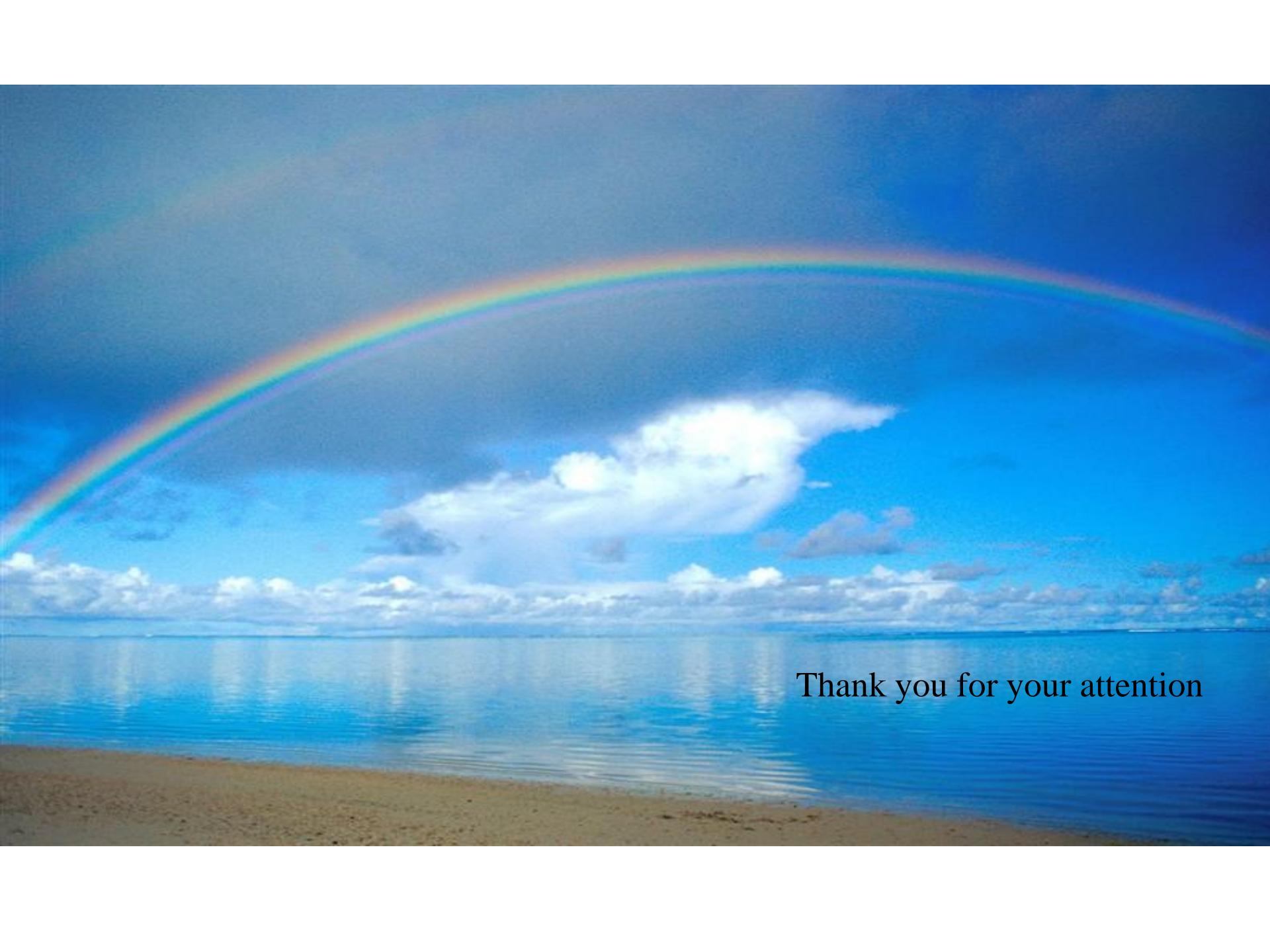
Outlook

In 2008, WGCM recommended the satellite simulators (COSP) to be used by the climate modelling groups participating in CFMIP-2 and CMIP-5 experiments (basis for the AR5/IPCC)



<http://www.cfmip.net>
<http://climserv.ipsl.polytechnique.fr/cfmip-obs.html>

Early 2011 should see the beginning of a strong activity on multi models cloud evaluation based on Atrain observations (ie. CFMIP-2, EUCLIPSE).

A wide-angle photograph of a bright rainbow arching across a clear blue sky. Below the sky is a calm, light blue sea with gentle ripples. The horizon line is visible in the distance. In the foreground, a sandy beach is visible at the bottom of the frame.

Thank you for your attention

- Supplementary material

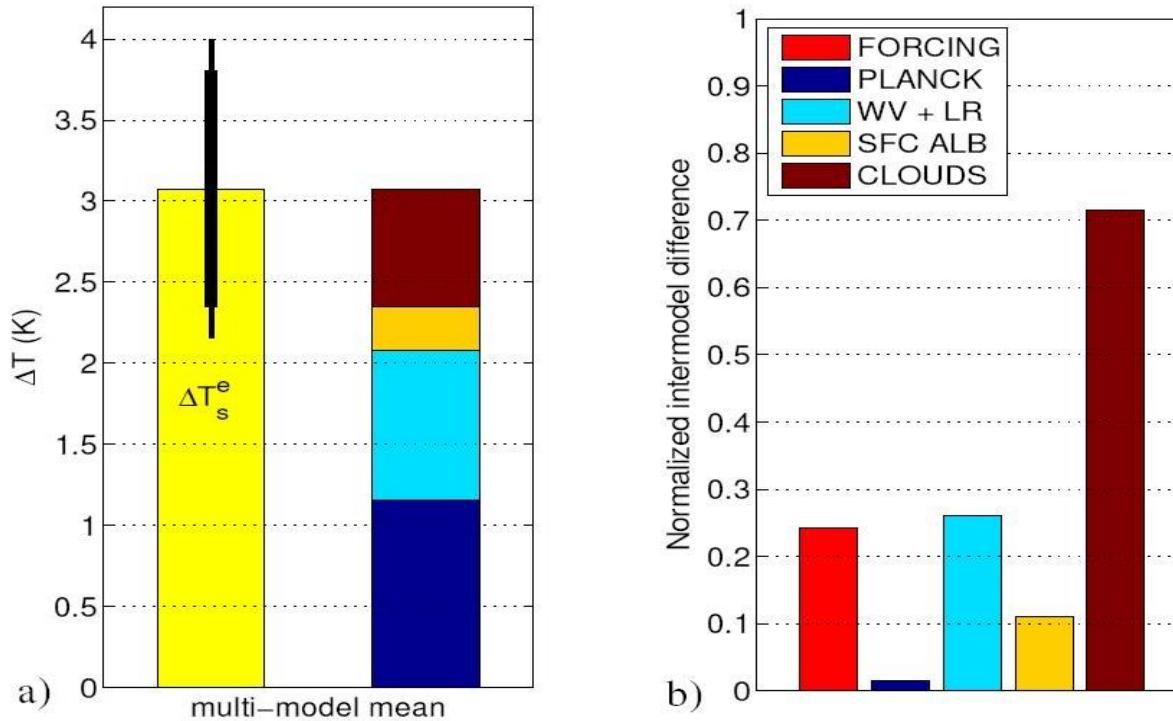


Figure 1: Pour un doublement de la concentration en CO₂, (a) moyenne ±1 dispersion standard (ligne épaise) et 5%-95% intervalle (ligne fine) du changement de la température d'équilibre. Contributions moyennes à ce réchauffement, dues aux différentes rétroactions : réponse de Planck, changements de la vapeur d'eau et du gradient de température, albédo de surface et nuages. (b) dispersion inter-modèles du changement de température associé au forçage radiatif, à la réponse de Planck, et aux différentes rétroactions normalisées par la dispersion standard du changement de la température d'équilibre entre modèles signalée à (a). [Dufresne and Bony 2008]

But :

The cloud cover derived from satellites is not directly comparable to model outputs
(vertical overlap, sensitivity of measurements, attenuation...)

Therefore :

To make models and satellites speak the same language, we use “simulators”
i.e. we diagnose from model outputs the quantities that would be observed by satellites
(e.g. radar reflectivities for CloudSat, lidar backscattered signals for CALIPSO)
if the satellites were flying above an atmosphere similar to that predicted by the model.

ISCCP (International Satellite Cloud Climatology Project) :

- data *widely and regularly* used for the evaluation of GCMs since the distribution of the ISCCP simulator (almost 15 years after the start of the program)

A-Train observations :

CFMIP has developed COSP (CFMIP Observations Simulator Package),

- a community software aiming at facilitating the comparison of GCM outputs with several observational datasets (ISCCP, CloudSat, CALIPSO, Parasol, etc).
 - distributed freely to climate & NWP modeling groups (20+ currently)
- CFMIP also distributes observational diagnostics consistent with simulator diagnostics

Model

LMDz GCM Outputs :

19 vertical levels, lat-lon $2.5^\circ \times 3.5^\circ$

LWC(P,lat,lon), IWC(P,lat,lon), $R_e(P, lat, lon)$

SCOPS :

Subgrid Cloud Overlap Profile Sampler
Cloud condensate / Cloud fraction / Cloud
overlap assumption

19 vertical levels, lat/lon : a few km or m

Imposed by model parametrizations:

Particle shape hypothesis
(spheres / non spherical)

Parameterized optical properties
 $P(\pi, z)$, Cdiff(z), Cabs(z) for liq, ice

Simulated lidar profile- lidar equation:

Multiple scattering coefficient = cste

Molecular signal from (P,T profiles)

$SR_{GCM}(19P, \ll 330m \gg)$

Same cloud diagnostics for model and obs at the same resolution :

Cloudy ($SR > 3$), Clear ($SR < 1.2$), Fully attenuated ($SR < 0.01$), Unclassified ($1.2 < SR < 3$)

Spatial homogeneity index, Cloud top height, SR diagram, Phase index, etc...

Observations

CALIOP L1 data:

583 vertical levels, 330m along the track

Attenuated Backscatter ATB (z, lat, lon),

Molecular density (33z, lat, lon)

GOCCP: Gcm Oriented Cloud Calipso Project

Compute ATBmol :

- scale molecular density to ATB in cloud / aerosol free regions (22-26 km)
- average over 10km (SNR)

Convert altitude in pressure (GMAO)

ATB (583P, lat, lon), ATBmol(583P, lat, lon)

Average over the 19 vertical levels

(same as GCM one)

Strong increase of SNR

$SR_{Obs}(19P, 330m)$



Statistics spatially and temporally obs and model diagnostics

Monthly / Seasonal diagnostics lat-lon $2.5^\circ \times 3.5^\circ$

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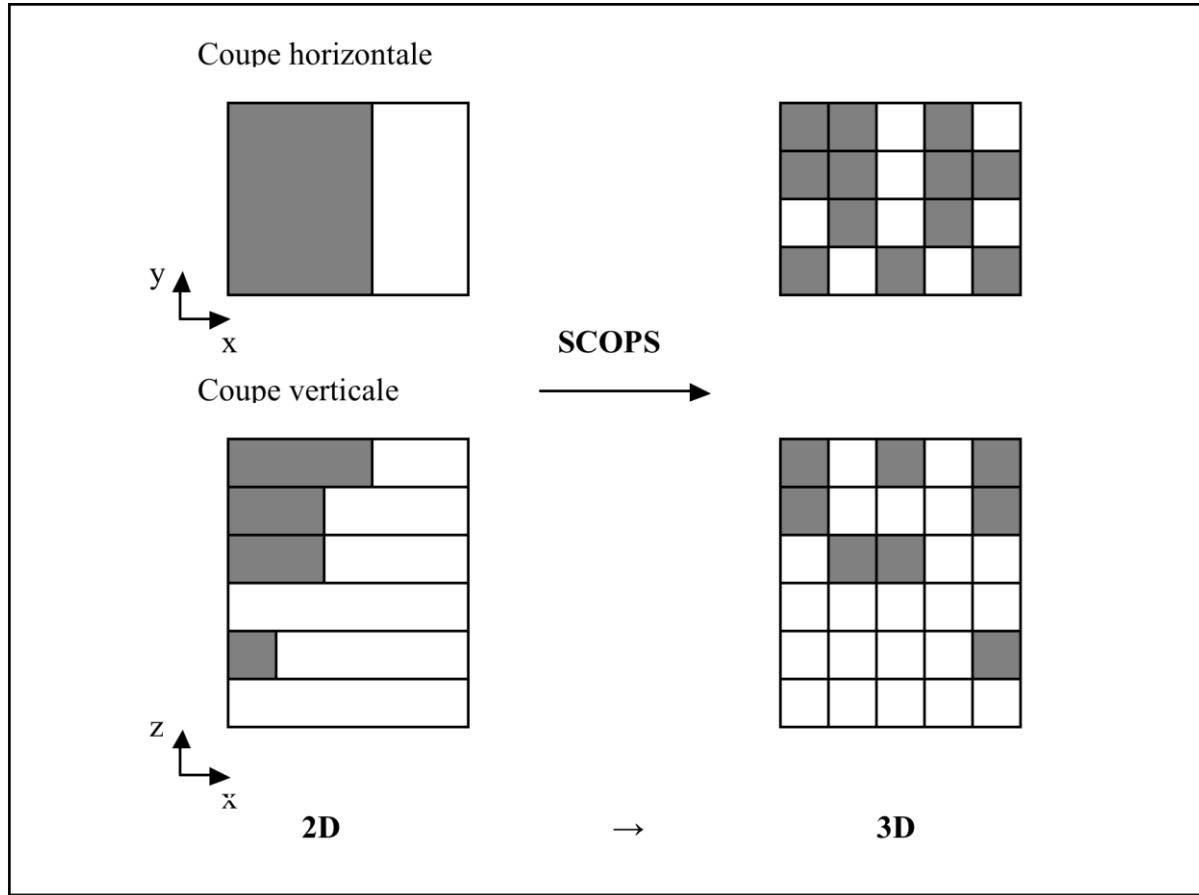
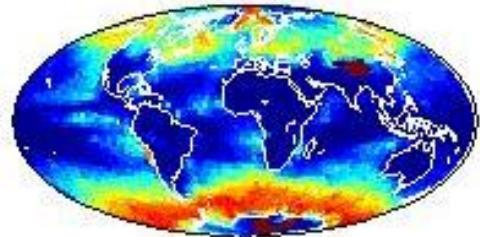


Figure 1.2 : Schéma de l'effet du module sous maille SCOPS : Une grille du modèle avant l'utilisation du SCOPS (à gauche) et après sont utilisation (à droite). La partie grise correspond aux nuages et la blanche au ciel clair.

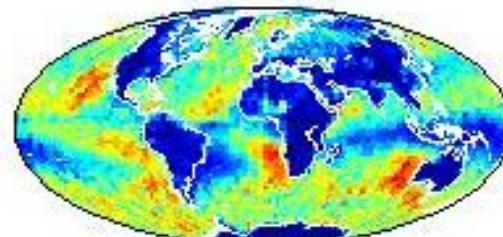
Klein and Jacob, 1999

Low Clouds

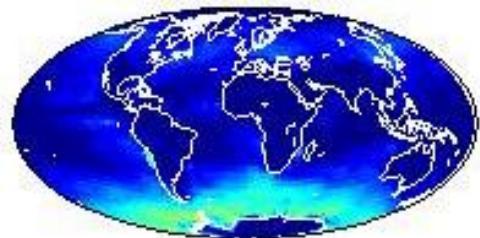
(e) LOW CLOUDS : GCM + LIDAR SIMULATOR



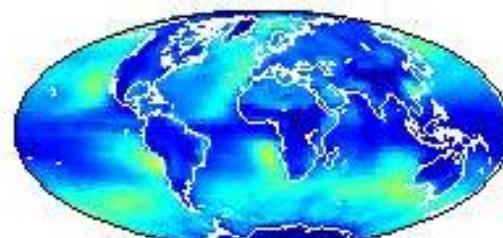
(f) LOW CLOUDS CALIOP



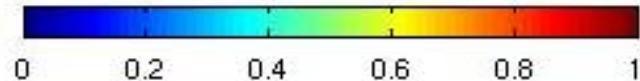
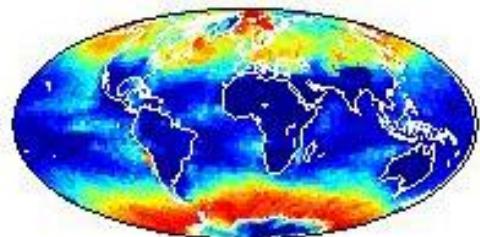
(g) LOW CLOUDS: GCM + ISCCP SIMULATOR



(h) LOW CLOUDS ISCCP

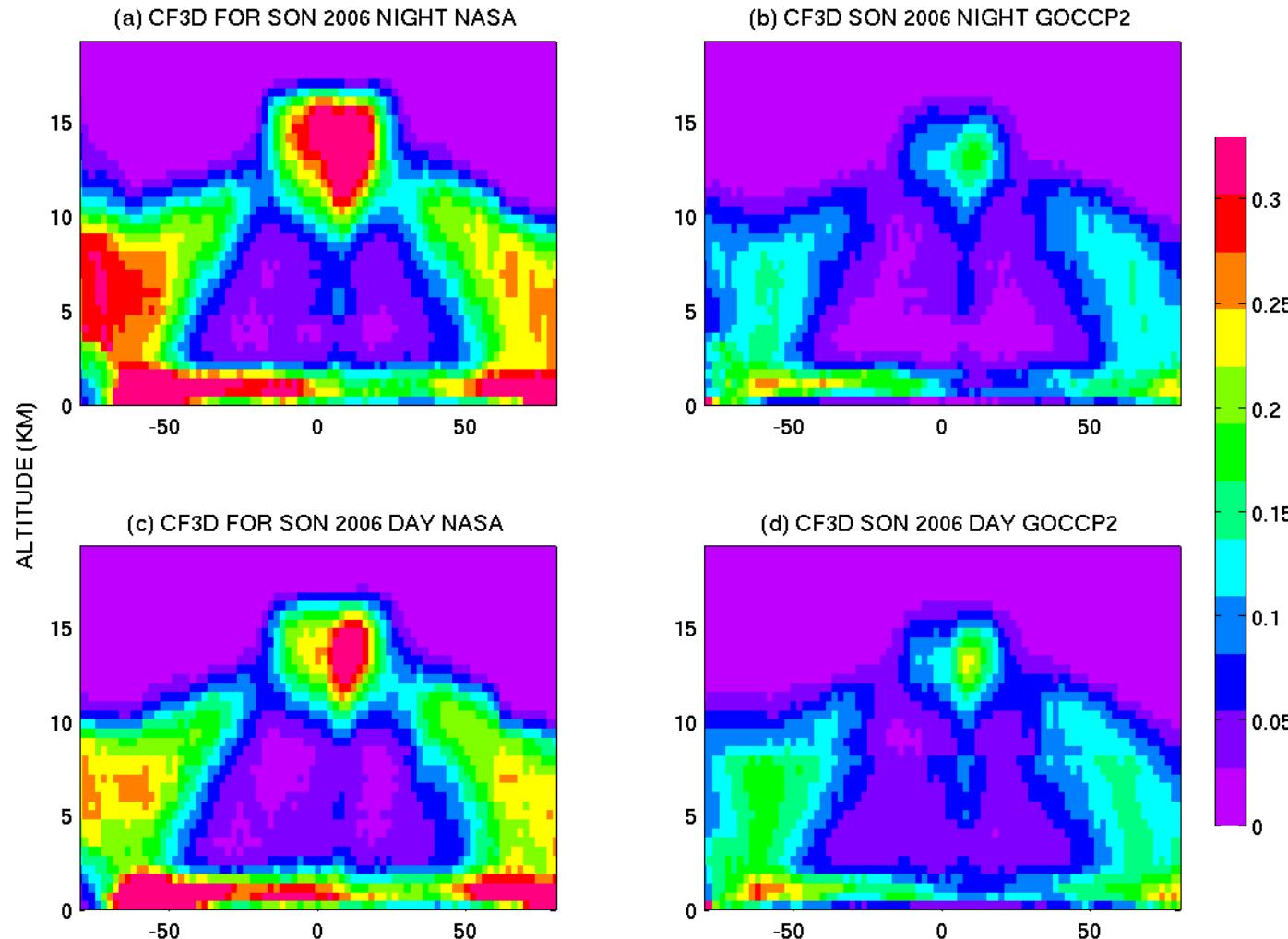


(i) LOW CLOUDS GCM



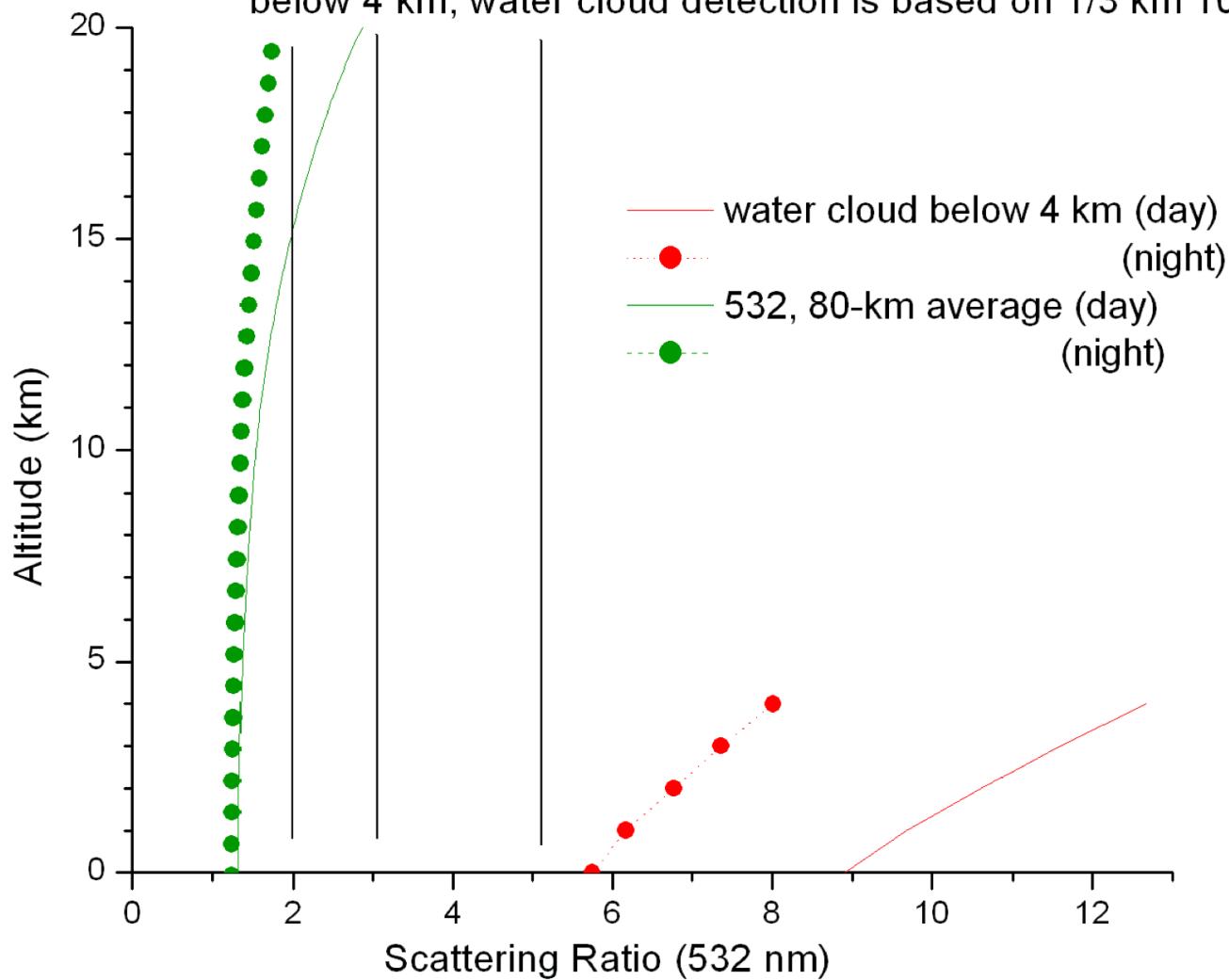
Comparison

3) 3D Cloud Fraction



« Comparison of two different cloud climatologies derived from CALIOP-Level 1 observations: CALIPSO-ST and CALIPSO-GOCCP », G. Cesana, H. Chepfer, D. Winker, B. Getzewich, in preparation

80 km is maximum averaging for ice cloud
below 4 km, water cloud detection is based on 1/3 km 1064



‘nouvelle physique’ comprend principalement :

(1) Un nouveau schéma de couche limite combinant un modèle en diffusion turbulente avec équation pronostique pour l’énergie cinétique turbulente et un schéma ‘en flux de masse’ pour représenter les structures cohérentes de la couche limite convective sèche ou nuageuse [Rio and Hourdin, 2008]. (2) Une version modifiée du schéma de convection profonde d’Emanuel (modification de la prescription de probabilité de mélange avec l’environnement, fermeture et déclenchement basés sur les caractéristiques de la couche limite) [Grandpeix et al., 2004]. (3) La prise en compte des poches froides créées par réévaporation des pluies convectives. Ces poches froides sont utilisées en retour pour le déclenchement et la fermeture de la convection [Grandpeix et Lafore, 2010].

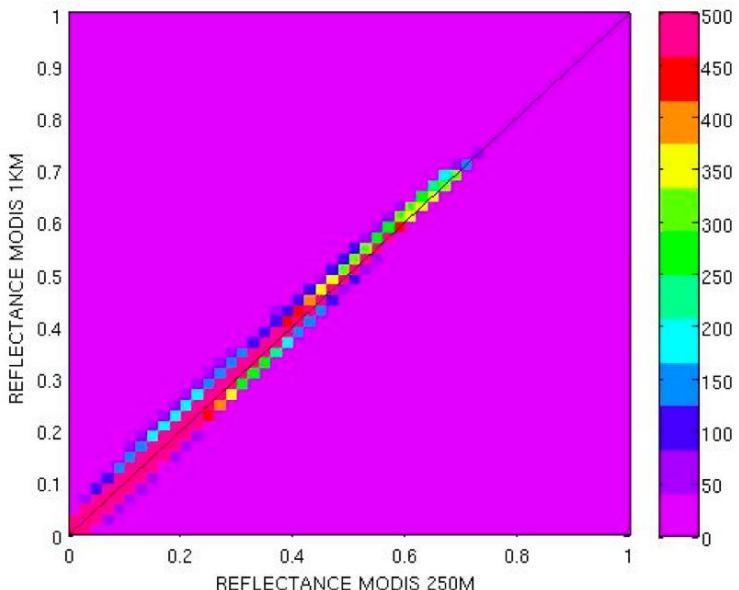
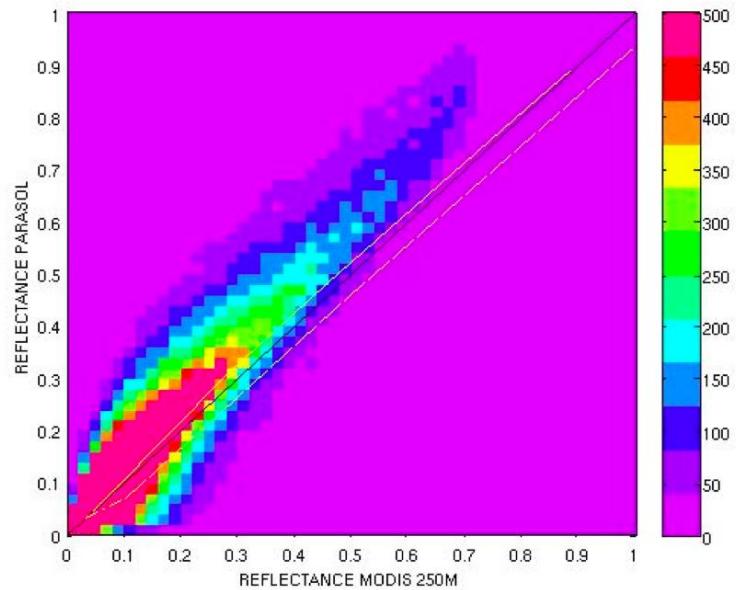
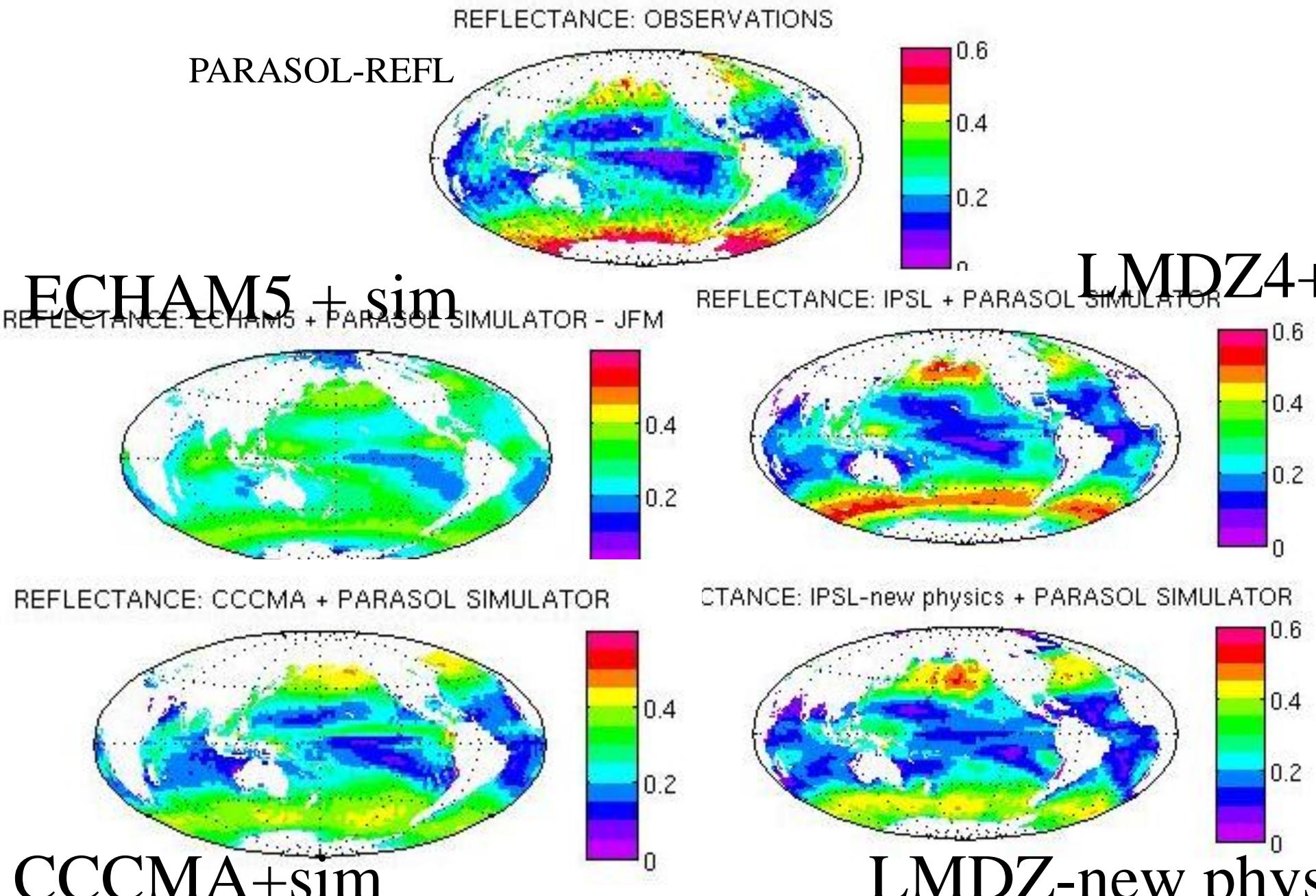


Figure 2.11 : Corrélation de la réflectance entre a) MODIS 250m et PARASOL 6km et b) MODIS 250m et MODIS 1km pour les océans tropicaux sur des grilles de $1^\circ \times 1^\circ$ pour deux ans des données.

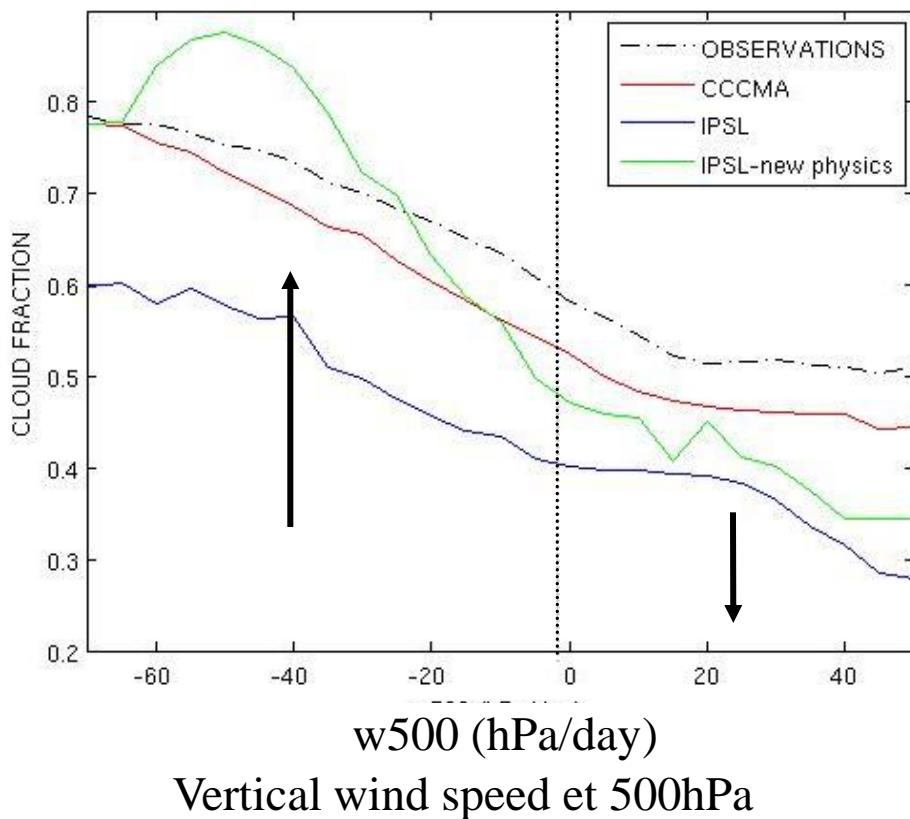
(d3) Cloud optical thickness model evaluation



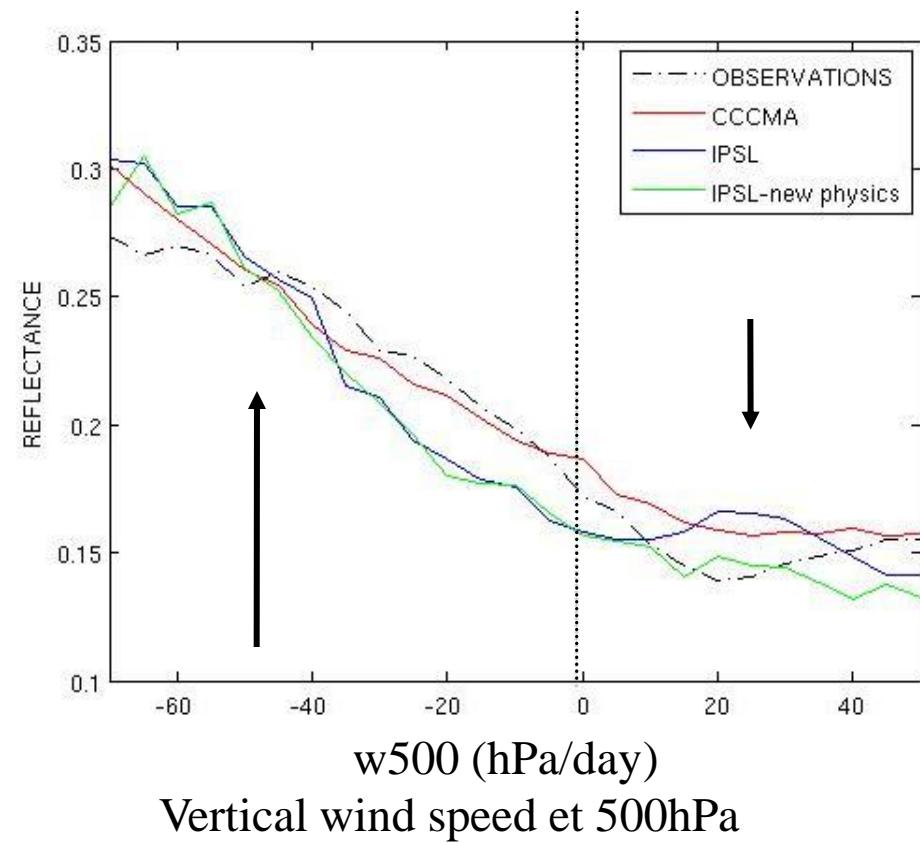
Focus on Tropics

(d1) Cloud cover and (d3) Optical thickness in dynamical regimes

(d1) CLOUD COVER



(d4) REFLECTANCE



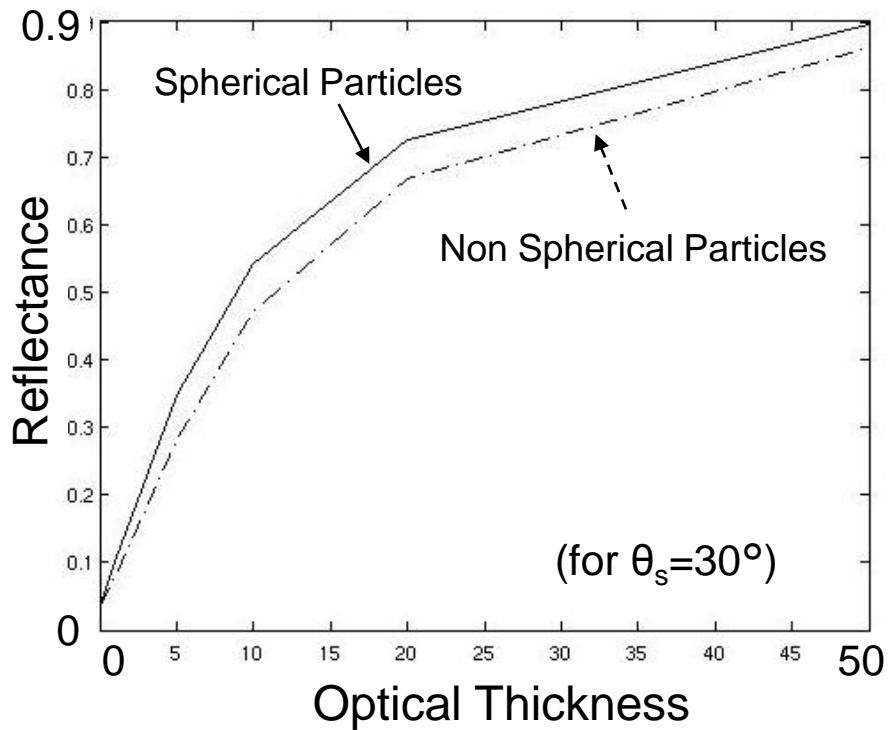
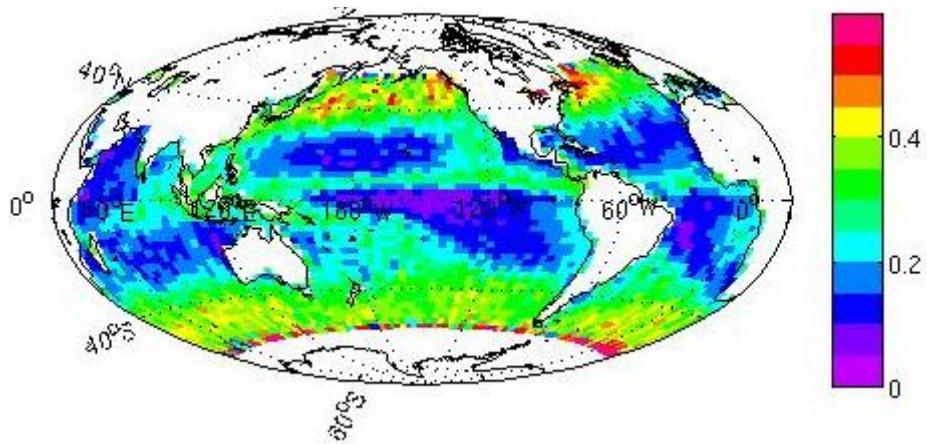
Error compensations between Cloud cover and

Clouds Optical depth (or Reflectance)

Radiometer PARASOL: directional reflectances, selection of one constant single direction ($\theta_v=30^\circ$, $\phi_s - \phi_v=320^\circ$)

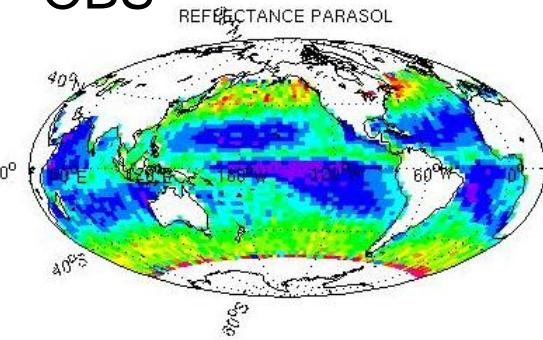
↳ Reflectance is a proxy of optical thickness

PARASOL
Reflectance 1constant direction



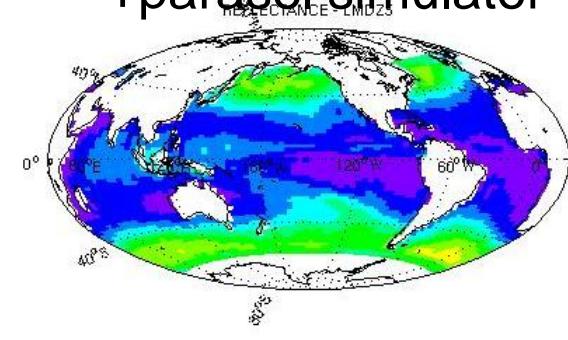
Cloud Cover and All Sky Reflectance – monthly mean

PARASOL 1con.dir.
OBS

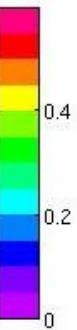
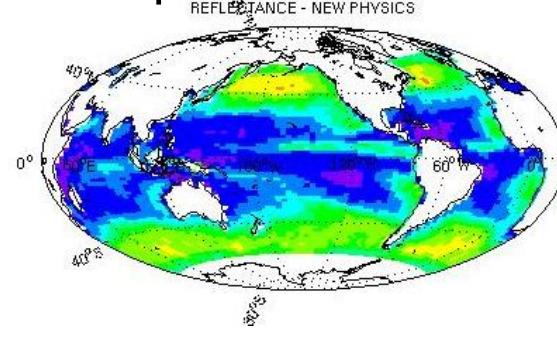


ALL SKY REFLECTANCE

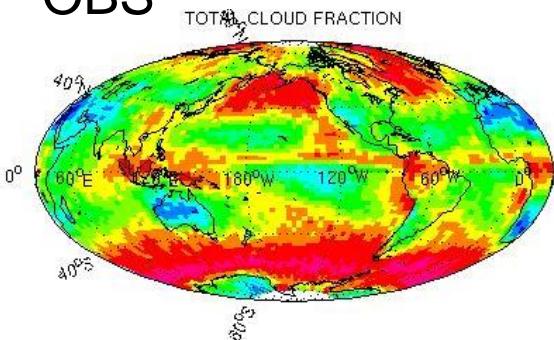
LMDZ5
+parasol simulator



LMDZ New Physics
+parasol simulator

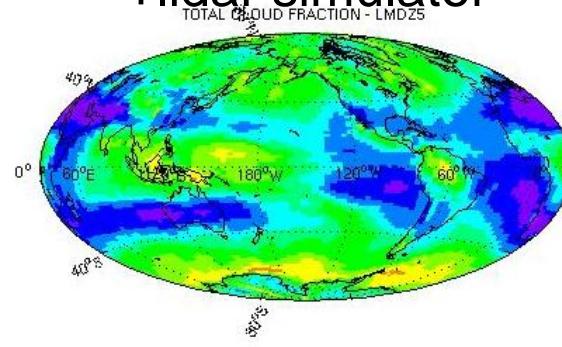


CALIPSO-GOCCP
OBS

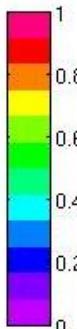
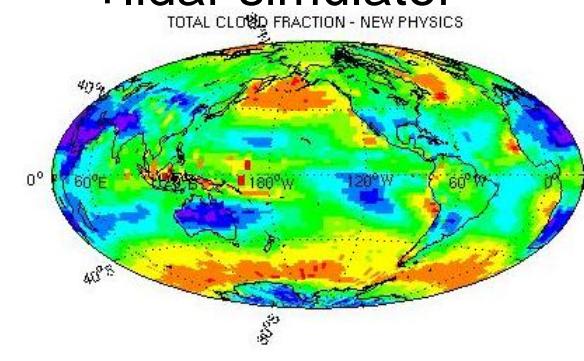


CLOUD FRACTION

LMDZ5
+lidar simulator



LMDZ New Physics
+lidar simulator

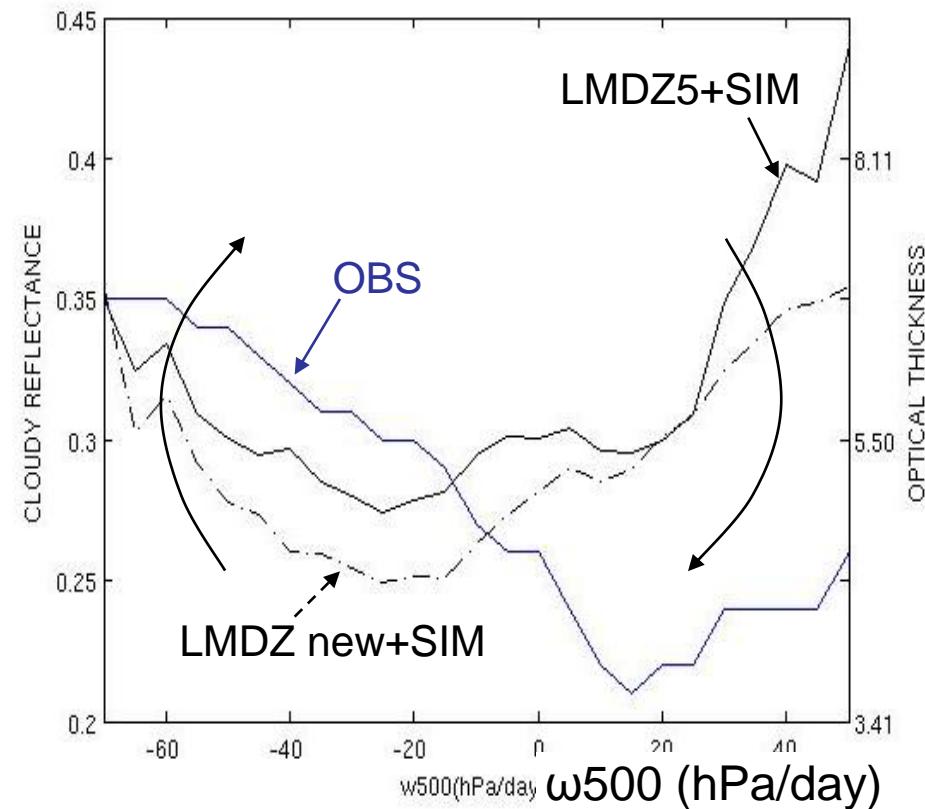


Error compensations between Total Cloud Cover and Optical depth
(vertically integrated value within the lat x lon grid box)
→ Need to evaluate the cloud parameterizations in climate models

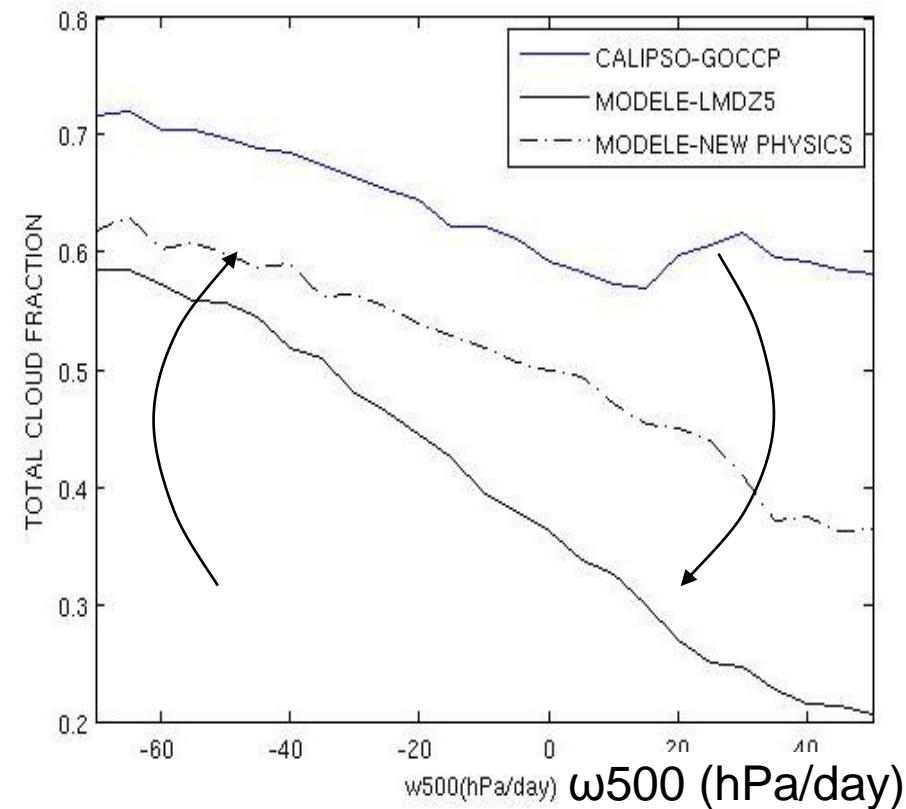
Cloud Cover and Cloud Optical Depth in circulation regimes - Monthly mean

Tropical ocean

CLOUDY REFLECTANCE



CLOUD FRACTION



- Subsidence regimes:

strong underestimation of cloud fraction but strong overestimation of cloud optical depth
(less from LMDZ New Physics)

- Convective regimes:

underestimation of cloud cover and cloud optical depth

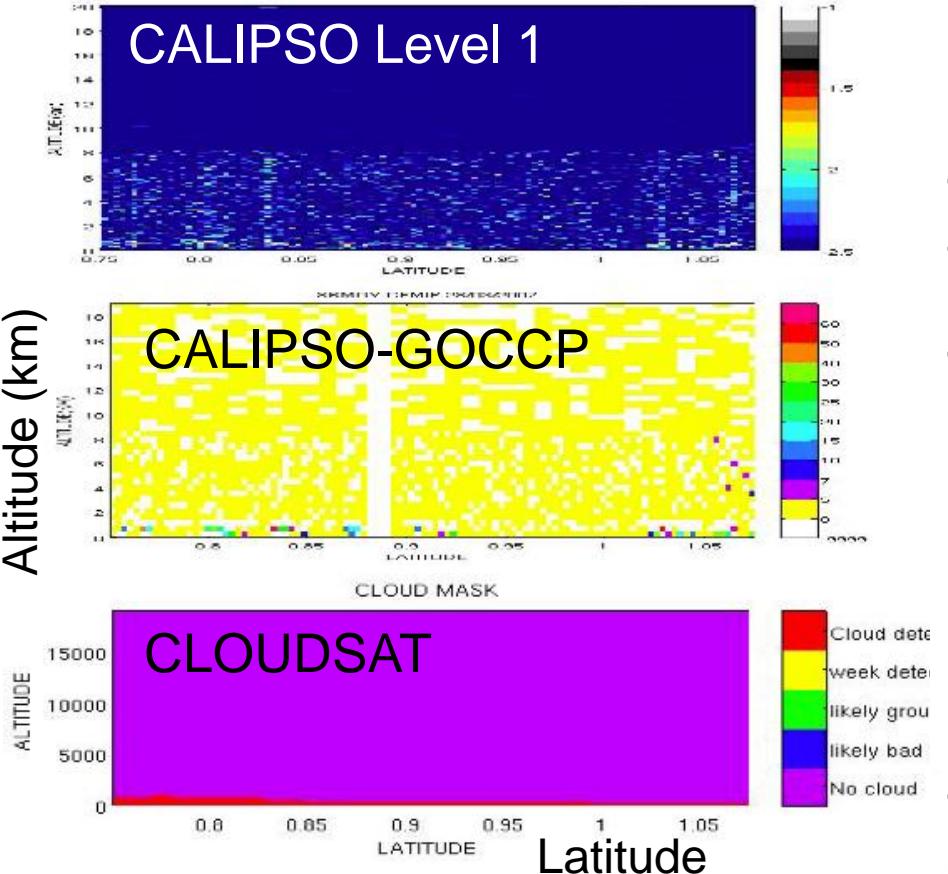
→ Need to evaluate the cloud parameterizations in climate models

- To evaluate the cloud parameterizations in climate models:

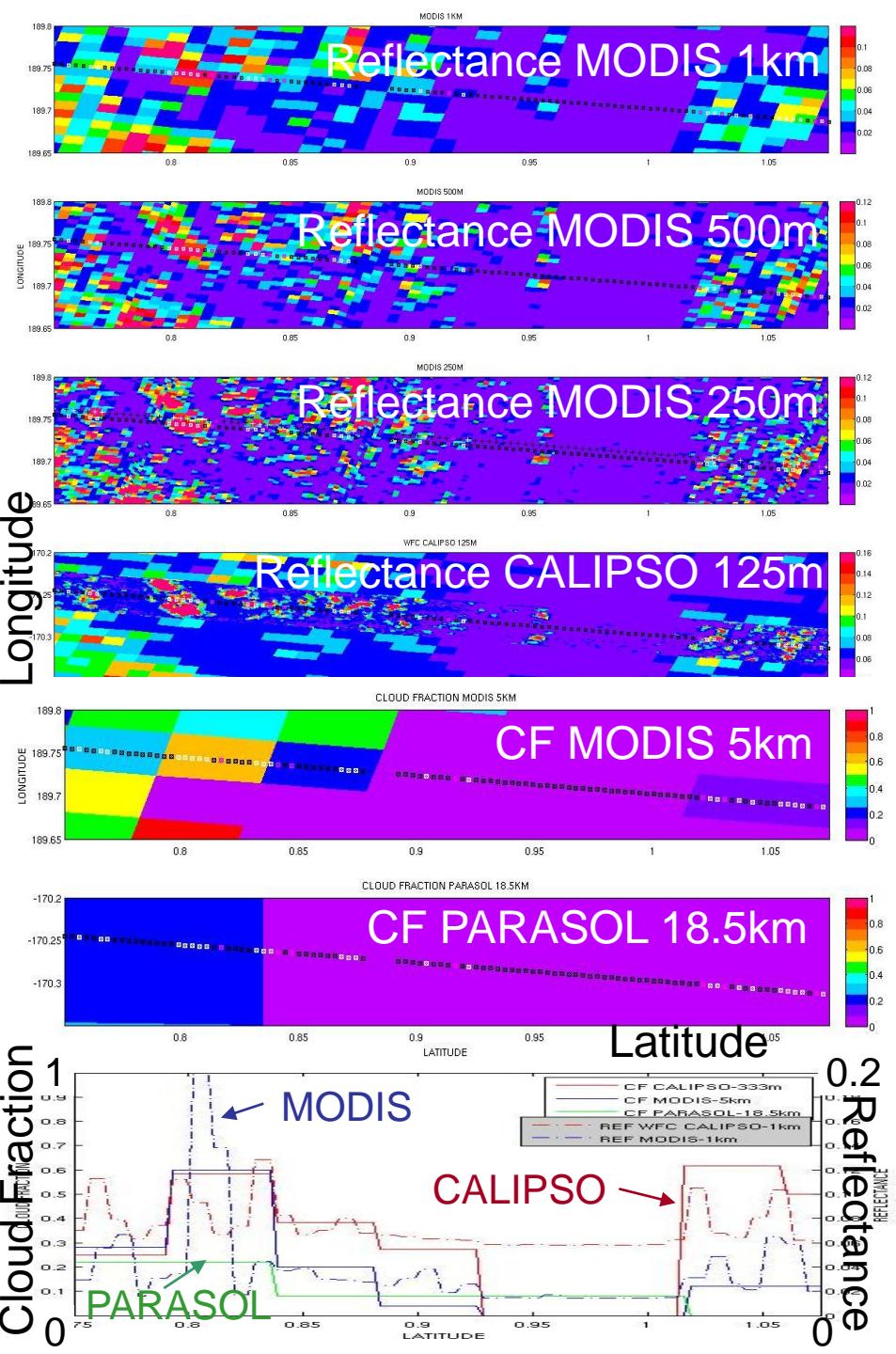
Monthly mean observations are not sufficient

We need to use high resolution (spatial and temporal) observations

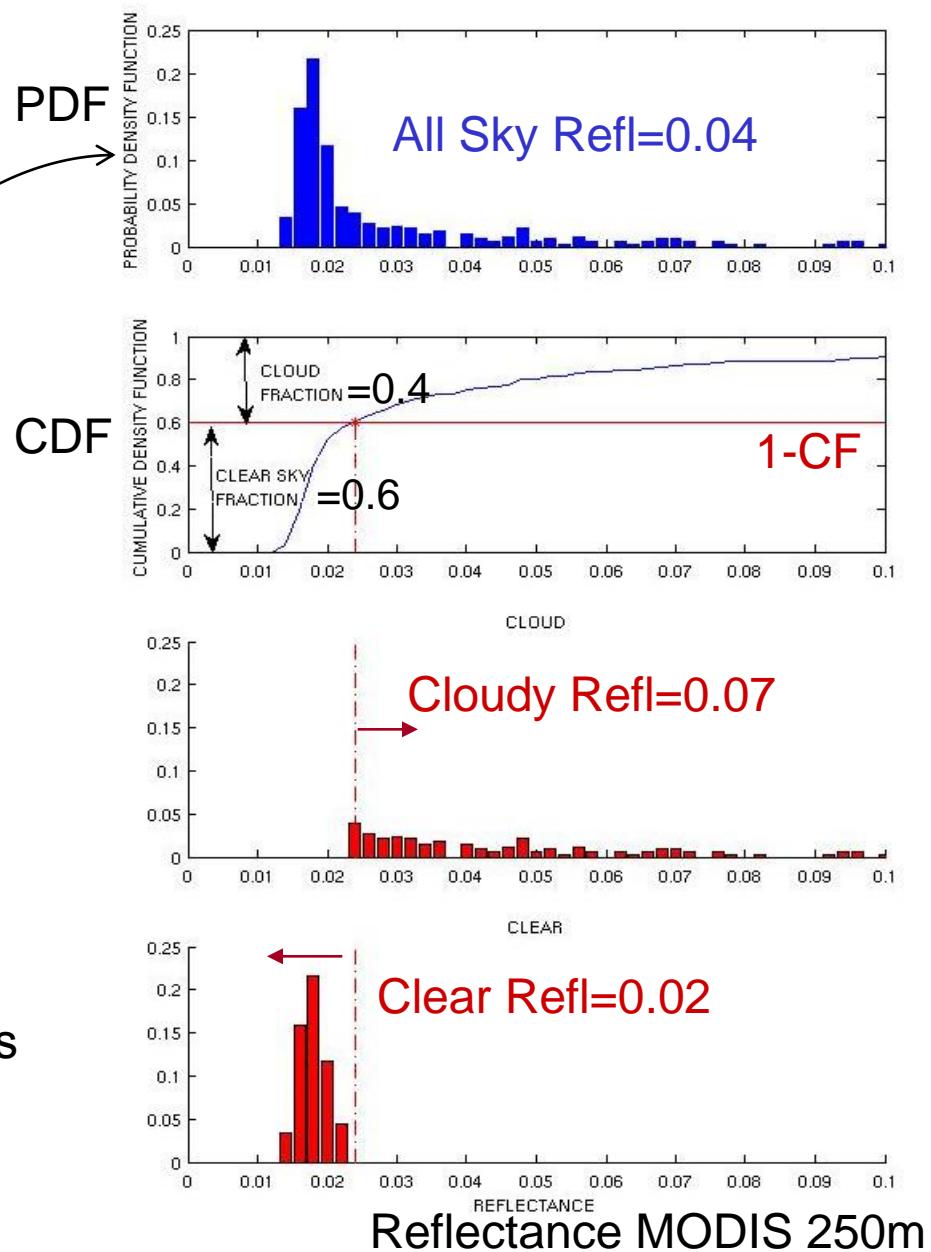
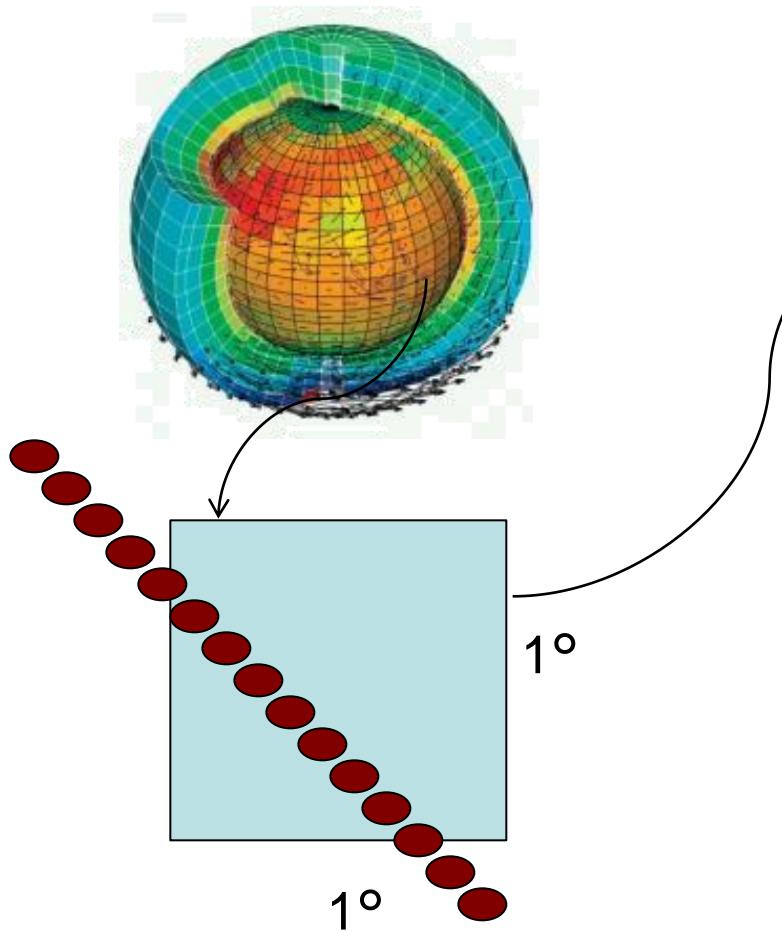
A case study: low tropical boundary layer clouds - high resolution obs -



Impact of the spatial resolution of the sensors
Need a clean separation clear/cloudy
Need colocated and simultaneous observations



A methodology: from the case study to global statistics using high spatial resolution data



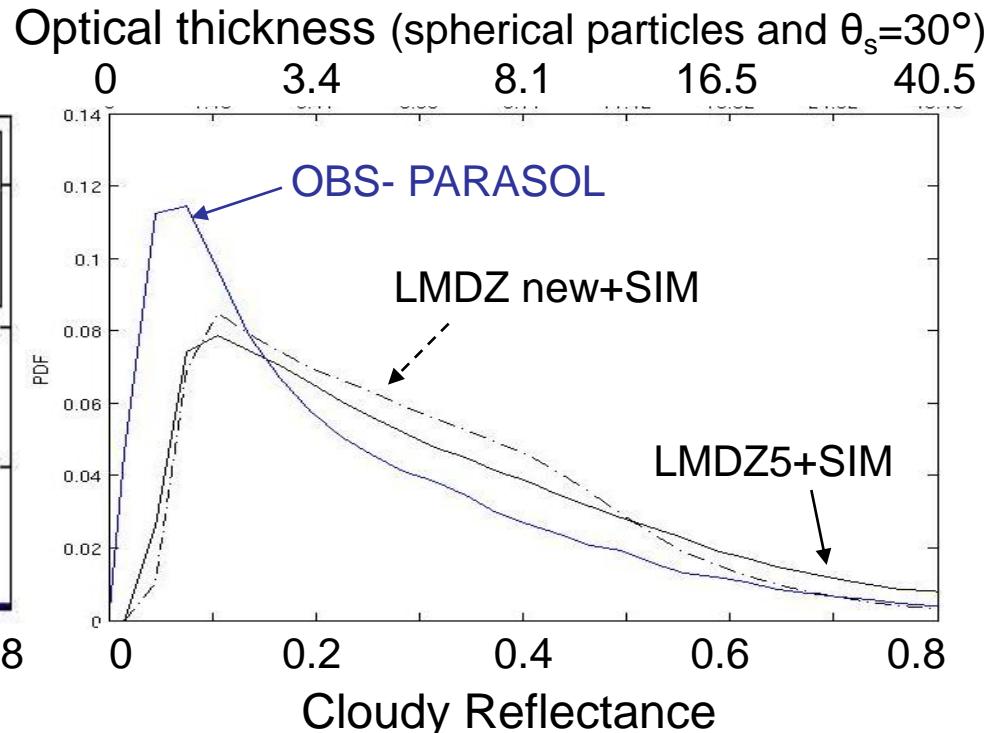
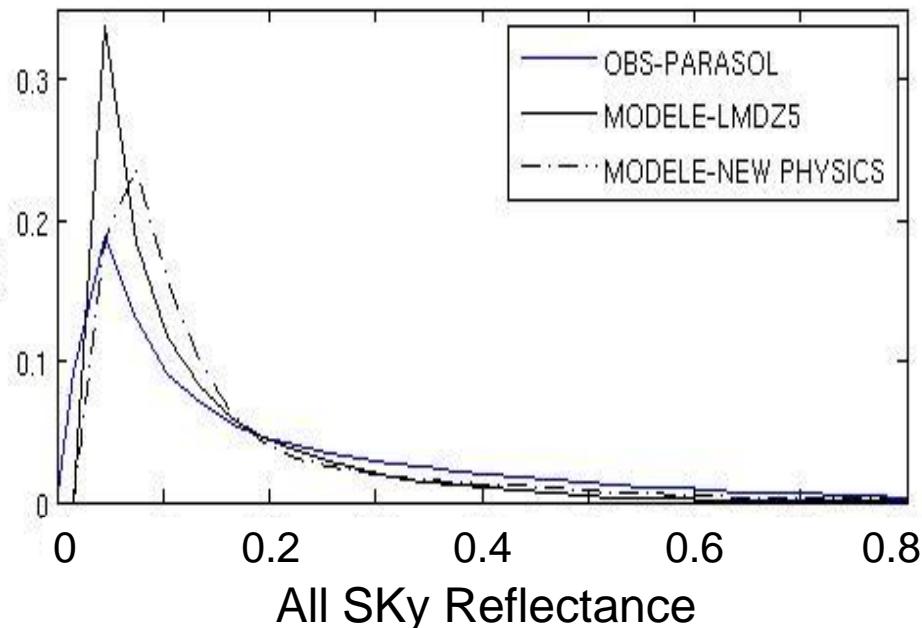
Same methodology for simulator's outputs
⇒ In each grid box (obs/mod):
Cloud Fraction and Cloudy Refl

Cloud Optical Depth

Evaluation of the model at high resolution

Tropical ocean

PDF



→ Overestimation of low values of All-Sky Reflectance and underestimation of high values.

BUT for cloudy reflectance (no clear sky contribution):

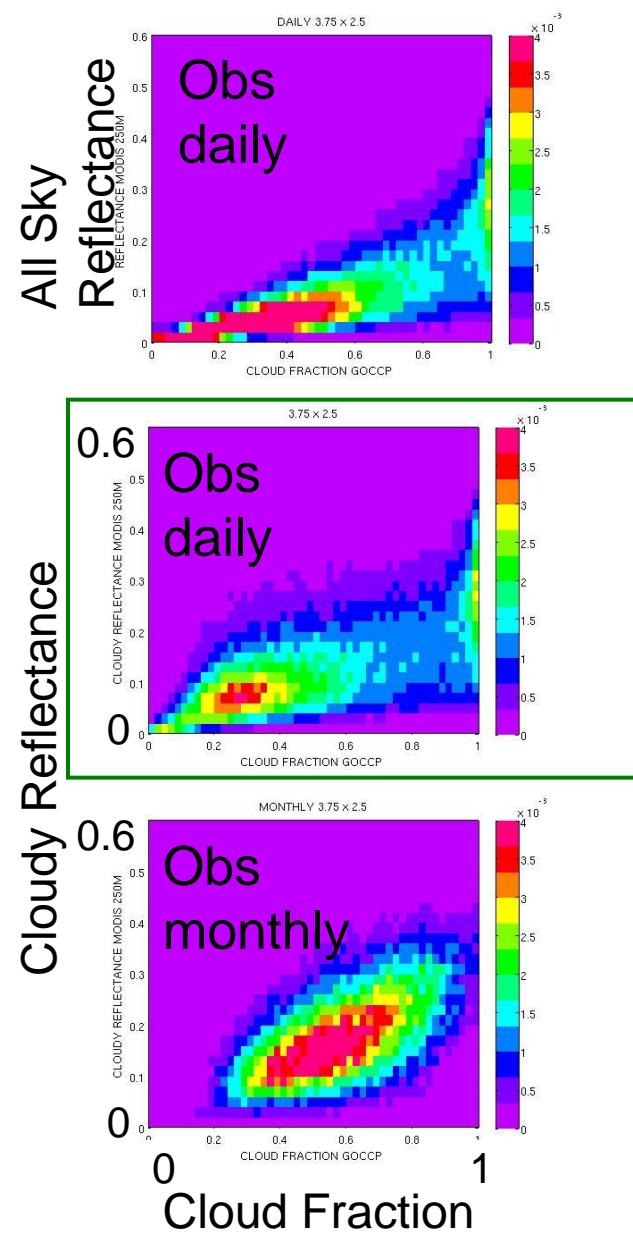
→ More optically thick clouds and less optically thin clouds simulated.

Corresponding CDF: 50% of the cloud:

Obs optical depth = 2.6
Models cloud optical depth = 4.8

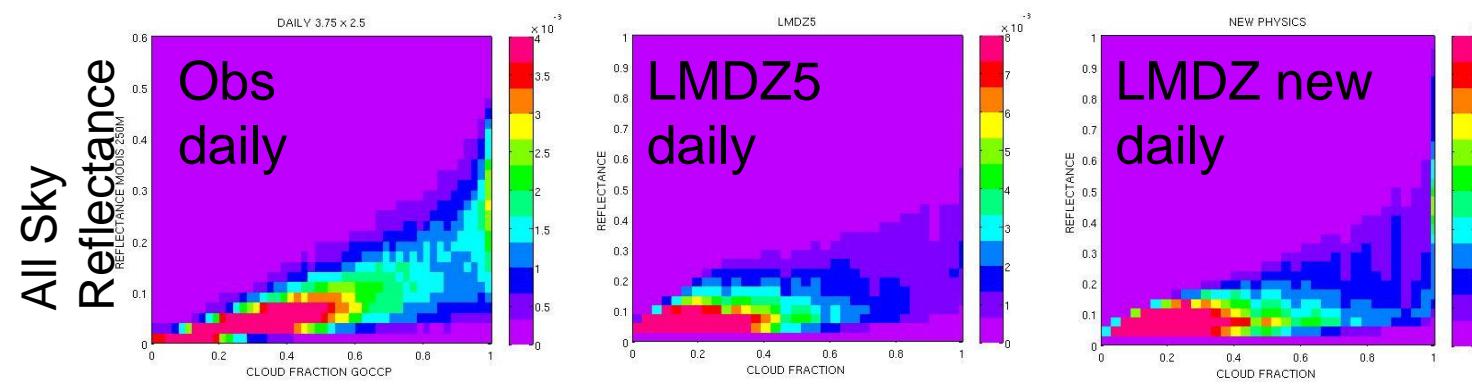
Relationship between Cloud Cover and Cloud Optical Depth

OBSERVATIONS Tropical ocean



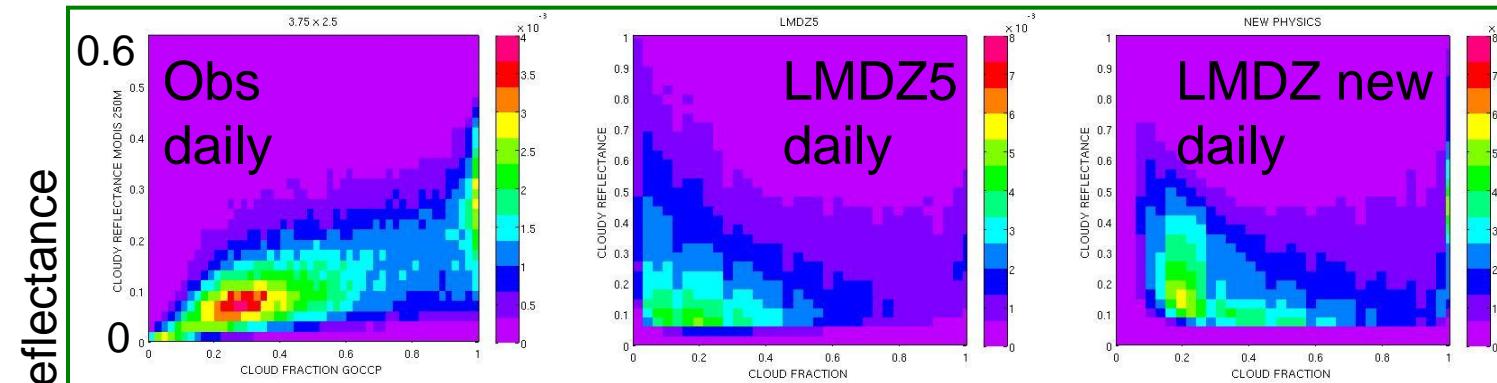
→ The relation between optical depth and Cloud Fraction changes with the scale of averaging changes in time (monthly.vs. daily) and in space (all sky .vs. cloudy)

Relationship between Cloud Cover and Cloud Optical Depth

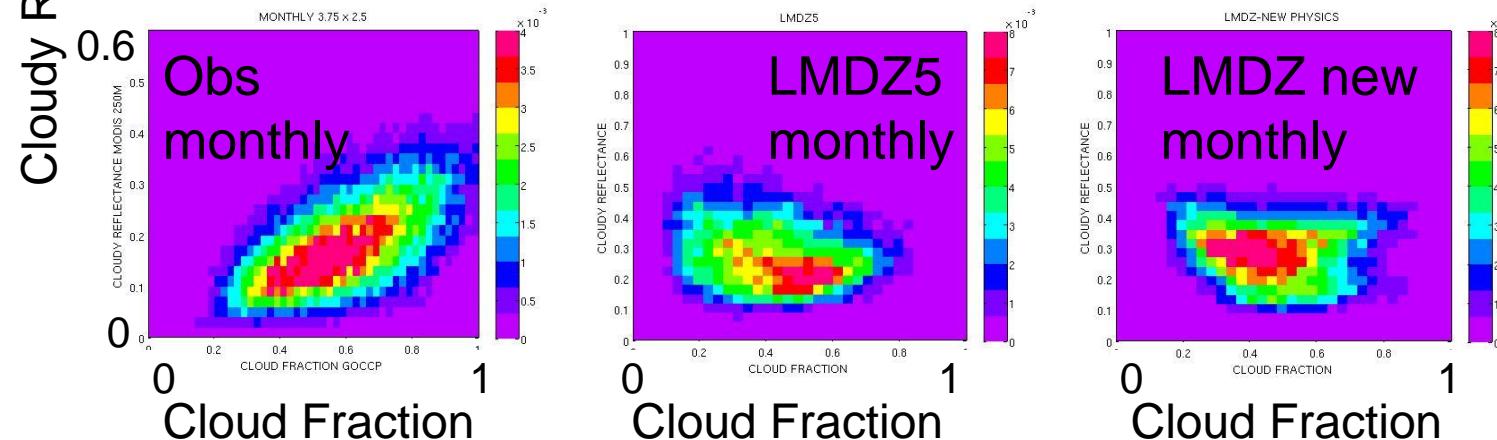


Tropical ocean

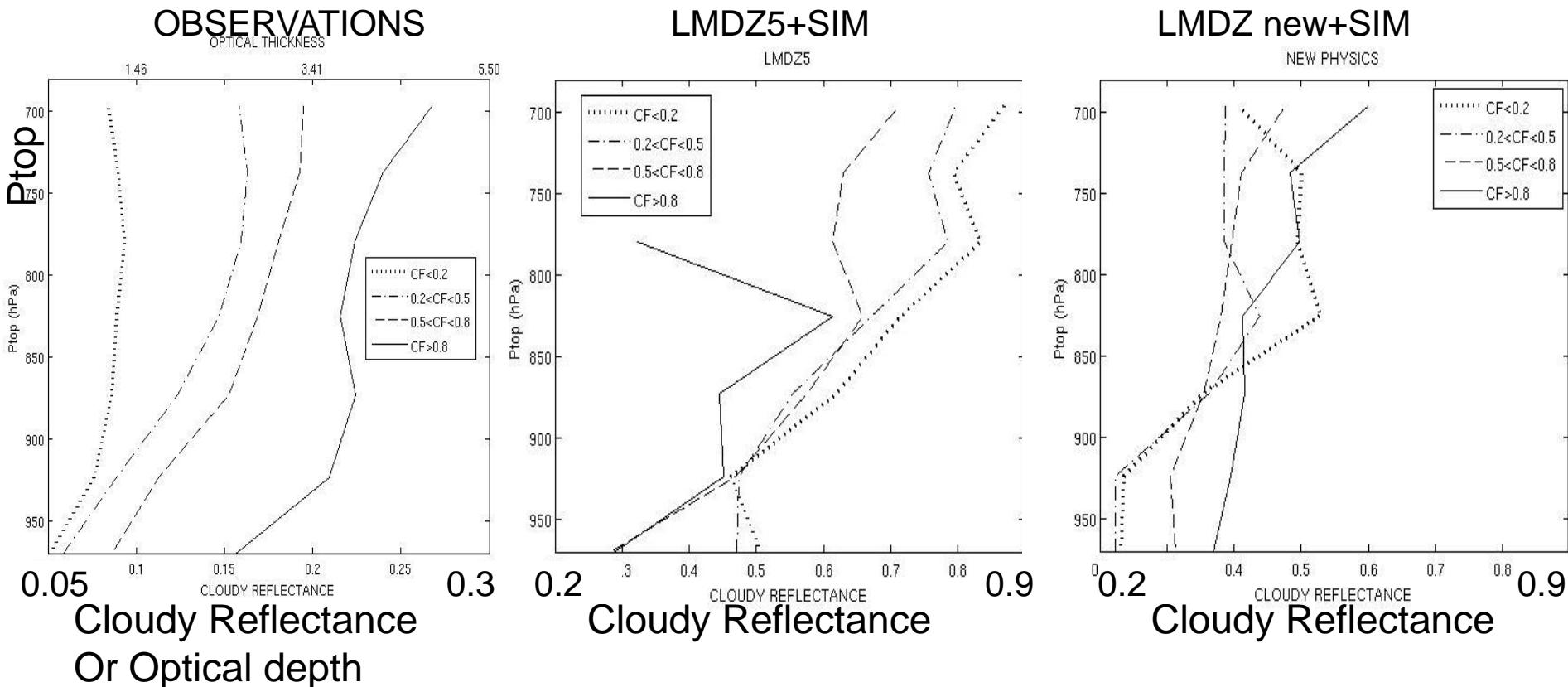
→ Model has difficulties to reproduce the ‘instantaneous’ relationship



=> Here after, we use « High Resolution » :
Cloudy Refl, Daily



Focus on low level boundary layer clouds: Relationship between the Cloud Top Pressure and the Cloudy Reflectance Tropical ocean



- OBS: The cloud optical depth increases with the cloud top altitude (and with the cloud cover) → the cloud grows vertically (and horizontally)
- Difficulties of the model to reproduce the relationship

0.03<REF<0.07

0.07<REF<0.18

REF>0.18

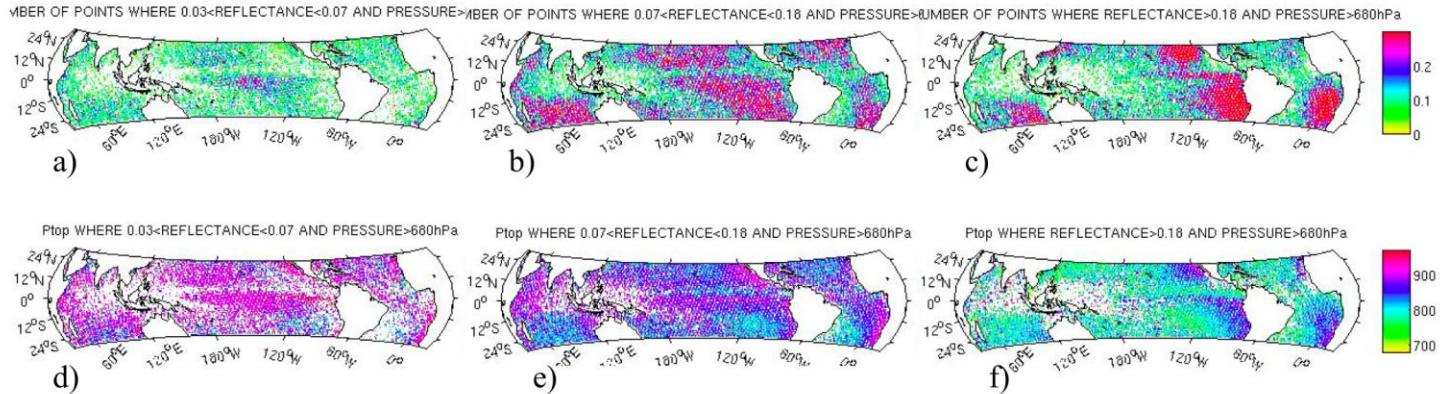


Figure 4.19 : Distribution géographique en haut (a,b,c) du pourcentage des points pour les nuages océaniques tropicaux de la couche limite par rapport à l'ensemble des points observés par CALIPSO et en bas (d,e,f) pression du sommet des nuages correspondante (définie comme le premier point depuis le haut pour lequel $CF3D>0.1$), selon leur épaisseur optique : (a,d) pour $0.03 < \text{réflectance nuageuse} < 0.07$, (b,e) pour $0.07 < \text{réflectance nuageuse} < 0.18$, et (c,f) pour $\text{réflectance nuageuse} > 0.18$. L'analyse est fait à partir des données journalières CALIPSO-GOCCP et MODIS 250m co-localisées et moyennées sur grille.

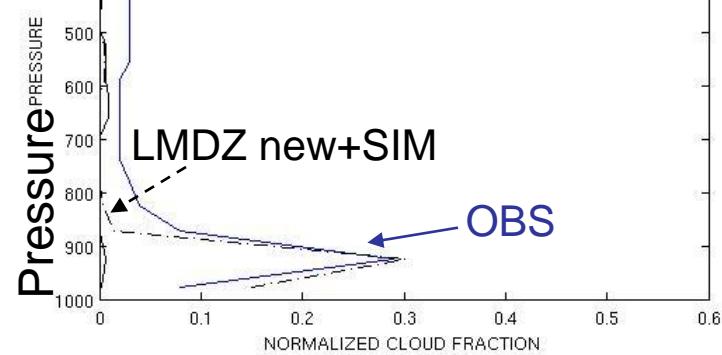
b)

Cloud Cover - Cloud Vertical Distribution – Cloud Optical Depth in circulation regimes

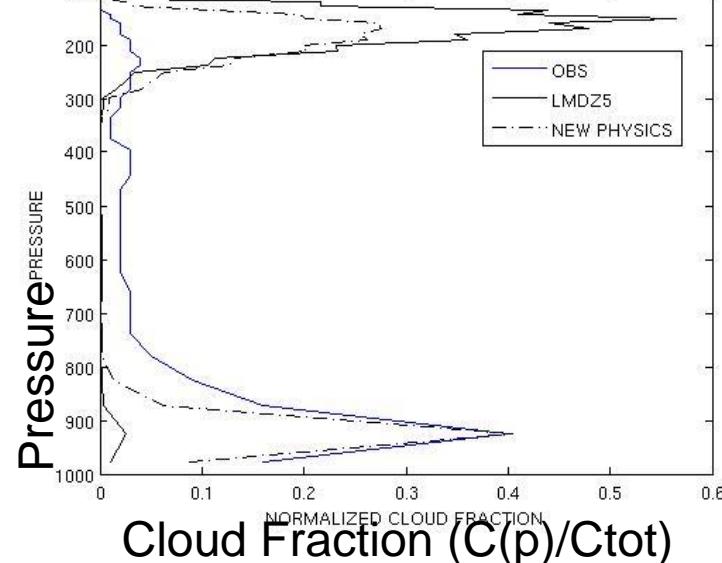
Tropical ocean

OPTICALLY THIN CLOUDS

CONVECTIVE REGIMES & $0.03 < \text{CLOUDY REFLECTANCE} < 0.1$

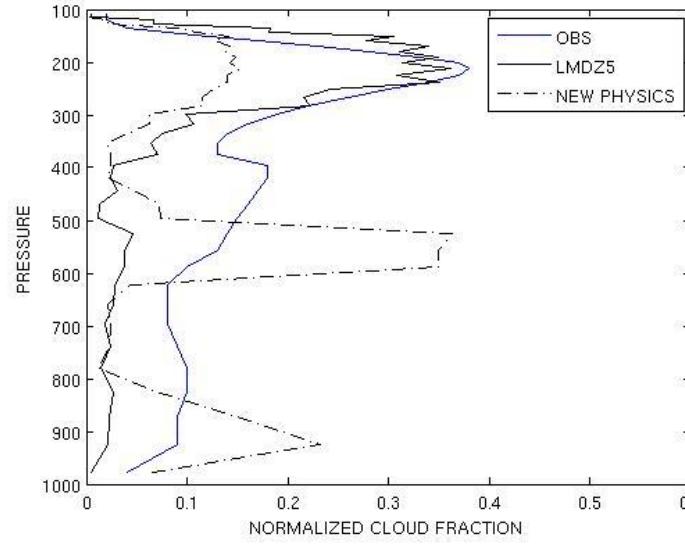


SUBSIDENCE REGIMES & $0.03 < \text{CLOUDY REFLECTANCE} < 0.1$



OPTICALLY THICK CLOUDS

CONVECTIVE REGIMES & CLOUDY REFLECTANCE > 0.25



SUBSIDENCE REGIMES & CLOUDY REFLECTANCE > 0.25

